BRIDGE
ENGINEERING

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BY

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CHAPTER XLV

EXPEDIENTS IN DESIGN AND CONSTRUCTION

In bridge engineering practice the term "expedient" may be defined as a method or detail of construction evolved to meet some new or unusual condition. What may properly be termed an expedient in one year may have become established practice in the next; for usually engineers very properly adopt everything new which is of real value in designing and construction. But, because of either the inherent modesty of bridge engineers or of their lack of time to make records, or possibly on account of the well known general disinclination of busy men to write for publication, many valuable expedients are used once or twice and then forgotten. To record some of these is one of the objects of this chapter, but its true *raison d'être* is to impress upon young engineers and students of engineering the fact that it is almost always possible to evolve some method of overcoming any obstacle that may arise in either the designing or construction of bridges, all that is requisite being an intense and earnest application of mental energy to the problem.

Knowing that in his own practice the author had evolved at various times expedients worth recording, and not wishing to illustrate this chapter by his own work alone, in 1907 he wrote to a number of his engineering friends and acquaintances who specialized in bridgework and asked them to cooperate with him by sending him descriptions of some of their expedients. A few of them complied with his request, but a number very modestly stated that they could think of no special work of theirs worth recording. The author regrets that his attempt was not more successful, and he takes this occasion to thank sincerely the gentlemen who did comply. He will now reproduce the salient portions of their letters before recording certain expedients of his own.

Edwin Thacher, Esq., C. E., of the Concrete-Steel Engineering Company, and well known both as a consulting bridge engineer and as the inventor of one of the best slide rules ever put upon the market, wrote as follows:

"I can think of but one expedient resorted to in my experience which is worth recording. It is as follows: A few years ago I was consulting engineer for a bridge across the Merrimac River at Newburyport, Mass. The Boston Bridge Works were contractors for the bridge, and Shailer & McCormick were subcontractors for the substructure, which was of steel cylinder piers filled with concrete. The bridge consisted of four fixed spans of 206 feet each, and a pivot span of the same length. The pivot pier was built of seven 6-foot cylinders, one of them being at the centre; and each of the other piers consisted of two 8-foot cylinders. The bridge had a 34-foot roadway and one

7-foot sidewalk, and was built to carry safely heavy loads. Soundings were made before work was commenced and it was supposed that rock would be reached from 40 to 60 feet below low water, the depth of water being from 20 to 28 feet. On reaching the depth at which it was supposed rock would be found, we were surprised to learn that there was no rock there within sounding distance, but we found a bed of small boulders mixed with sand and gravel instead. This kind of foundation was not considered safe to bear the load, consequently the difficulty was overcome by converting this bed of boulders and small material into concrete having a much larger area. The piers were put down by compressed air, and the following course was adopted. The pressure in the cylinder was relieved until about 4 feet of water came in. This body of water, the size of the cylinder and about 4 feet deep, was converted into a rich grout. The pressure was then put on, and this grout was sent down into the foundation, and the process repeated until it would take no more. It was found that this concrete spread out for considerable distance in all directions, for in grouting the second tube of any pier there was evidence that the grout used in the first tube had extended that far, so that the second tube would take less grout than the first.

"This course was followed for all the tubes, including those for the pivot pier, and I think without doubt that the foundation was converted into a mass of concrete, just as good as rock.

"This method can be followed very readily when compressed air is used, but not so readily when it is not used."

This expedient of Mr. Thacher's was truly a novel one and well worthy not only of record but also of adoption under similar conditions. It would be well to use it for all pneumatic piers that are not carried to bed-rock and which rest on material into which grouting can be forced.

The late Horace E. Horton, Esq., C.E., who for many years was one of America's most prominent contractors, especially in highway bridge-work, wrote as follows:

"I have in mind the doubling up, in fact even trebling up, of old spans as well as girders to fit the increased loading (a continuous performance of railroad demands). I have a case in mind of three 80′ spans—3-truss, double-track, half-through bridges, which were re-erected as one single-track, 3-truss, 80′ span deck bridge, and one 6-truss, single-track, 80′ span deck bridge. This is as an extreme example and even with three times the material to do the work it seemed desirable to add rivets at certain points.

"I am disposed to question whether reminiscences of this class would have any particular value. They surely are interesting as showing the extreme of economy in using up old material.

"We have on repeated occasions reduced a double-track bridge to a single-track one, cutting off the beams and using four stringers for a single track. We have rearranged two single-track-span deck bridges into one span. We have made two single-track spans from three-single-track, deck-bridge spans. We have formed two single-track spans into a single-span through bridge, using equalizers for floor connections to the two spans, and have riveted one track stringer immediately on top of another.

"I am not speaking of the above as a matter of novelty or merit, merely facts that the business presented itself in these shapes, which I presume it has done to all other manufacturing concerns in our line."

The eminent bridge engineer, Ralph Modjeski, Esq., wrote thus:

"Regarding expedients. At this time I can only mention a few which occur to me, as follows:

"In designing the Rock Island Bridge draw span, by certain requirements of the Commanding Officer under whose executive charge the bridge was being built, I was required to dispense with main pinions and gearing of the ordinary type. A sprocket chain gearing was therefore designed and has been operating very successfully, although I would not repeat this design on account of its expense and complication.

"During the construction of this draw span when the ice carried out one of the arms partly erected, both the railway and the river traffic had to be taken care of, and a lift span was improvised for that purpose. In this bridge there were also a few features of the erection which might be considered as expedients. All of these you will find in Appendix 5 of the Report to Chief of Ordnance, U. S. A., 1899.

"On the Thebes Bridge a number of expedients were employed both in designing and in construction. Those used in the foundations belong properly to the contractors, C. Macdonald & Co. of New York, who may be able to furnish you with some information.

"On the superstructure I would call your attention to an expedient at LSO for taking care of the expansion in the lateral system.* Also to the double pin arrangement at LOC, the object of the second pin being to relieve bending stresses in the bottom chord which would result from the simultaneous deflection of the two adjacent spans.† I send you the lithographs under separate cover.

"On the construction of the Willamette Bridge it was deemed advisable to lower the caissons from barges so that the barges could be placed and the caissons built at any convenient point. I am writing to Mr. Nickerson, Resident Engineer, to send you a photograph of this arrangement.‡

"I would also refer you to the *Transactions* of the American Society of Civil Engineers for some details of rail locks and end lifts which may properly be considered as expedients. These were shown in connection with the discussion of Mr. Schneider's paper on Draw Bridges."

A. F. Robinson, Esq., the well-known bridge engineer of the Atchison, Topeka, and Sante Fe Railway System, wrote thus:

"We, of course, have to adopt a good many expedients in our practice which do not work out very successfully. Perhaps one of the items that has caused the writer the most trouble has been the expansion bearings under long girders and under short truss spans.

"Some years ago, Mr. Onward Bates,§ in discussing details of design, advised that for shoes under girders the sole plates be beveled, leaving the bearing of the sole plates about 8″ in length, with sufficient width to distribute the loading into a cast base or a heavy wrought metal base. I adopted this scheme for our long girders from 70′ spans up.

"We used this plan for five or six years. Where the bridge pointed nearly North and South and where the pedestal stones were in one piece for the whole width of pier, or where they extended back through the parapet walls on abutments, we have had no trouble from the expansion. On the other hand, we have had several bridges which stood more nearly East and West in which the pedestal stones on the abutments or on the piers have pulled badly on account of the stress caused by the girders sliding on the bases. About three years ago we changed the detail for structures of this kind, using instead a heavy cast-iron base with a large lozenge-shaped rocker or disc. These rocker bearings have thus far worked very nicely.

"What I have been trying to avoid was the necessity for a lot of steel castings and

* See Fig. 45*a*. † See Fig. 45*b*. ‡ See Fig. 45*c*.

§ Past President of the American Society of Civil Engineers.

either segmental or cylindrical rolling bearings for girders from 70′ up and for short truss spans. Details of this kind always cost much more relatively than the remainder of the structure. What I have been trying to obtain all the time is a design which shall work acceptably and which at the same time will not increase the average unit cost for our structures."

Mr. Robinson's pedestal detail is so clearly explained as to need no illustration. It appears to be an excellent one. For small expansions and contractions it ought to serve its purpose admirably.

Henry W. Hodge, Esq., C.E., in a late letter, wrote as follows:

"We note that you also ask that we send you any "expedients" in design, which we have made use of, and we would say that the main expedient which we indulge in is in varying the length of panels, as is exhibited in our fixed spans in the St. Louis Bridge, and in the cantilever and draw span designs which we send herewith. We send you a print of the general stress sheet of the St. Louis Bridge, which will give you the varying panels, and we would also call attention to the expedient which we have adopted of running the end lower laterals to the centre of the floor-beam and thus avoiding the complicated detail adjacent to the end shoes.

"We also send you the general drawing and detail of the cantilever arm of the Chico Cantilever in Mexico, and you will note on this that we used a varying panel and a varying depth of lower chord in each panel, and we inserted the lateral plates between the outside of one chord and the inside of the other chord, thus taking up almost all the variation in depth of chords between panels. We also here used a half pin-hole in the outer member of the lower chord and in the vertical posts to facilitate erection; and this drawing also shows an expedient of ours in making latticed laterals of an odd number of panels on one member, and an even number on the other, so that the lattice bars pass through each other at the central intersection and do away with the large and ugly looking batten plates so generally used on such laterals.

"We are also sending you drawings showing a vertical gate at the end of draw spans, which we have used for the State of Connecticut, owing to the fact that we wished something that would prevent trolley cars and automobiles moving at high speed from going into the opening. We have never seen anything exactly like this, hence we believe it to be new; and it certainly works most satisfactorily. Some photographs of this gate recently appeared in the *Engineering Record*.*

"We are also sending you a blue-print of the draw span which we are building at Troy, which shows a type of highway floor that we have adopted as standard, and which we find saves a great amount of metal. We place the floor-beams at regular intervals (in the neighborhood of 10′) regardless of the panel points; in fact, we try to make this arrangement so as to avoid the panel points and thus do away with complications in connections. By this means we get all floor-beams exactly alike. The stringers are in such short lengths that they can be made extremely light and of rolled sections, and we find that the amount added to make a stiff lower chord still leaves the total weight of the floor very much below that of a floor composed of long stringers with short cross beams to hold the flooring. We generally use a reinforced concrete slab floor, but on this draw span we have used 5″ plank to save weight. While, of course, on a draw span we would require a stiff chord in any event, we use this same type of chord for fixed spans with a very considerable saving.

"You will also note that in the top laterals of this span we make a considerable saving in weight by running a central longitudinal strut and using single angle diagonals, thus avoiding the deep latticed laterals which would otherwise be required for rigidity."

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* See the issue of September 19, 1914.

Mr. Hodge's expedient of varying the panel length with the depth of truss is a good one, as it adds to the appearance of the structure. It

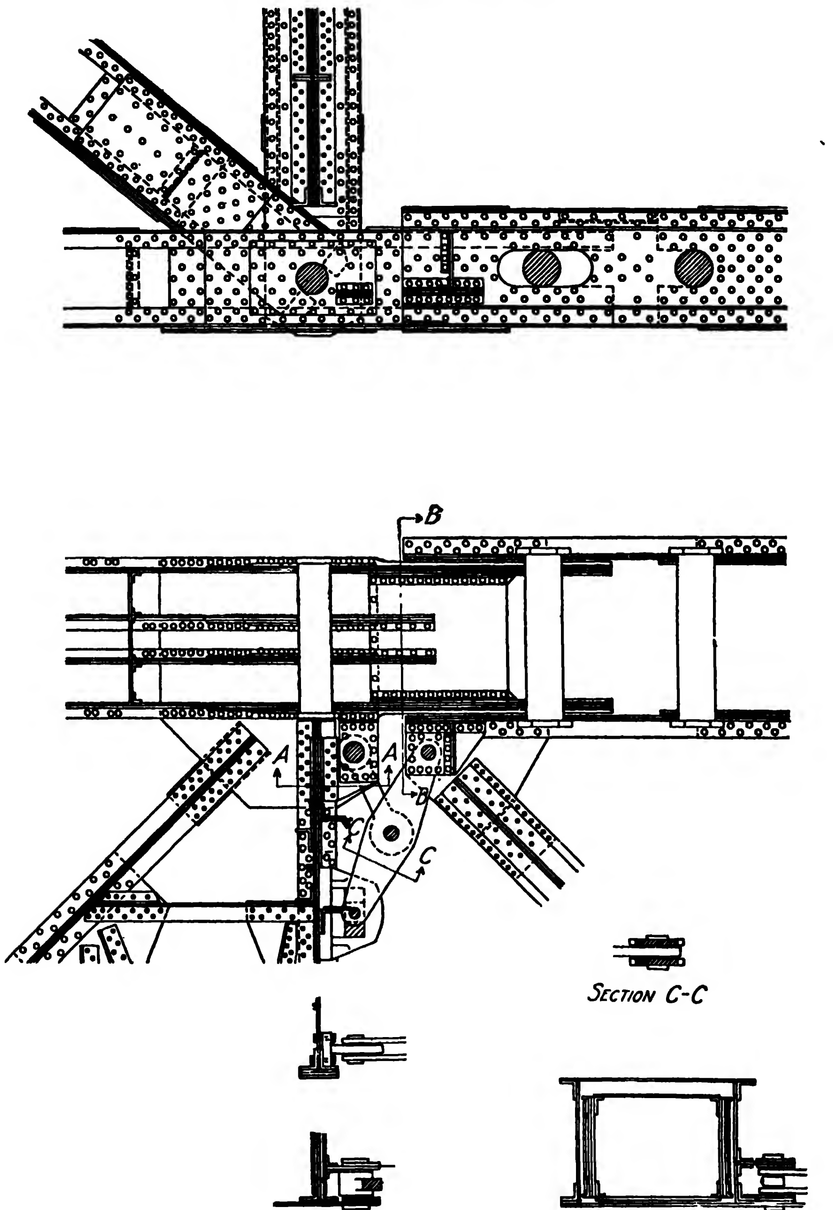

FIG. 45*a*. Details of Expansion Joint in the Lateral System at the End of the Suspended Span of the Thebes Bridge.

would have been adopted by the author long ago had it not been for the opposition of the bridge shops. In the opinion of almost everybody

connected in any way with the manufacture of structural steel, it has been rank heresy for anyone to think for an instant of varying the panel length, excepting only at the ends of skew spans, the objection being the lack of duplication involved; and the shops have had such influence on the bridge engineers as to keep them in line on this question until Mr.

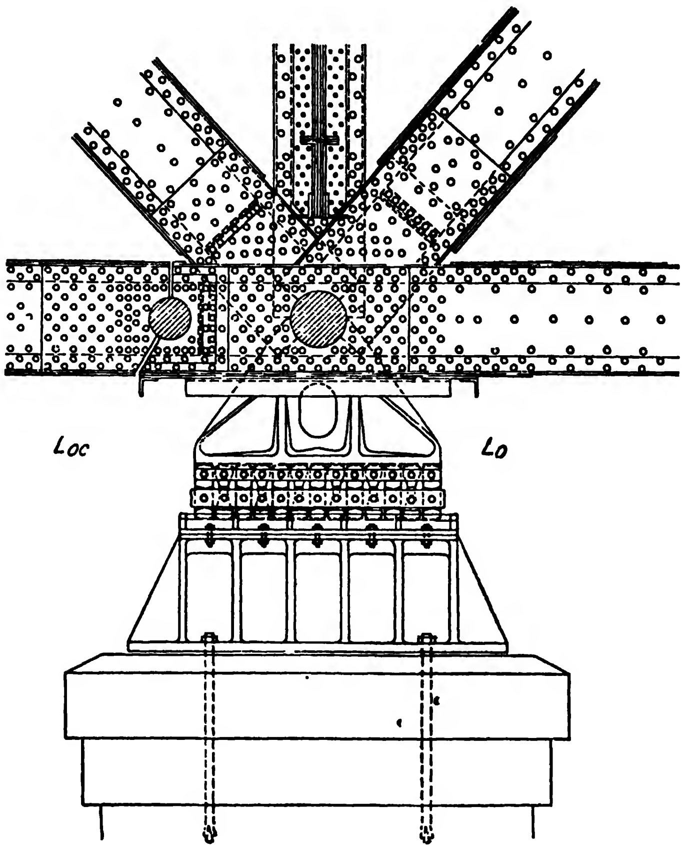

FIG. 45b. Details of the Bottom Chord Joint at the Piers of the Thebes Bridge.

Hodge had the courage to break away from the established precedent. The practically parallel diagonals of the trusses in the long spans of the St. Louis Free Bridge certainly add greatly to the appearance of the structure.

Mr. Hodge's detail for connection of end lower laterals is a good one. When hearing about it for the first time, one might be inclined to think that it involves weakness by putting bending moment on the end floor-beams; but such is not the case, for the bringing together of the two end laterals gives them the function of end chord members of the horizontal lateral truss, thus cutting out the end panels of the bottom chords from aiding to form the said truss. The great advantage of this detail, as

pointed out by Mr. Hodge, is the avoidance of complicated detailing adjacent to the end shoes.

Mr. Hodge's expedient of varying the depths of the compression chords in the Chico Cantilever works very well with a pin-connected structure, but it would not apply so nicely to a riveted one. The same remark applies, of course, to his half-hole expedient, which necessarily is confined to pin-connected construction.

The expedient of having an odd number of lattice panels in one of two intersecting lateral diagonals and an even number in the other, thus cutting out entirely the stay plates at the crossing of the struts by letting one pair of lattice bars or lattice angles intersect at the panel point of the system of latticing in the other diagonal, is certainly excellent. It should be adopted universally; for it is a money saver under all conditions. One should make sure, though, that the splice plates for the cut strut are large enough to develop the full strength of the strut in either tension or compression.

The type of floor system for the Troy Bridge is all right whenever it shows an economy of metal; but it is possible that the old standard type might prove the more economical under certain conditions. As far as excellence goes, there is nothing to choose from between the two types, the question at issue being simply one of cost.

The author does not like Mr. Hodge's last expedient, for it utilizes single angle irons in tension. He has himself employed the central longitudinal strut, in some cases continuous from end to end of the lateral system and in others broken, in order to stiffen and reduce the sections of the transverse struts, but has adopted either two angles laced or four angles in the form of an I with lacing or latticing for the lateral diagonals.

The strengthening of an old bridge by putting in a middle truss, as in the Niagara and Poughkeepsie Cantilever bridges, is an expedient worthy of notice. Descriptions of these two pieces of work will be found in the files of the technical press.

In *Engineering News* of August 15, 1907, there is illustrated a most peculiar expedient, viz., the building of trusses curved in plan so as to avoid obstructing traffic on the quay beneath. In the author's opinion, the expedient was not a legitimate one; for, as pony trusses were used, and as the extent of the influence of l over r on that kind of a truss, even when on tangent, is quite problematical, it appears like an unnecessary assumption of serious risk to aggravate the condition by curving the top chord, especially as the latter seems from the illustrations to be none too adequately stiffened, what side bracing there is being entirely on the inside. The structure referred to is the Austerlitz Bridge over the Seine in Paris. The mathematical study of the stresses in this peculiar type of structure was made by the famous French Engineer, Monsieur Jean Résal, Chief Engineer of *Ponts et Chaussées,* hence it is not at all likely that any mistake has been made in the computations; nevertheless an

American bridge specialist when looking for the first time at either the picture in *Engineering News* or the actual structure itself can hardly help feeling that he himself has been given an actual torsional wrench.

An expedient was employed many years ago by the late C. Shaler Smith in the Lachine Bridge, a single-track railway structure over the St. Lawrence River near Montreal, by which the main span was constructed as a cantilever for the dead load and after connection at the middle was used as a continuous girder for the live load. The method, while novel, was not altogether satisfactory, mainly, perhaps, because

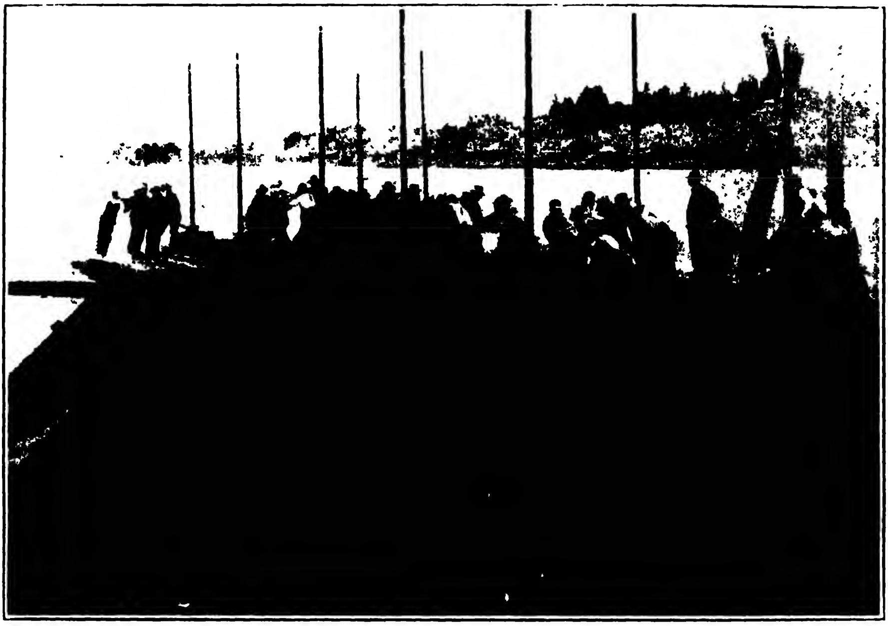

FIG. 45c. Lowering a Caisson from Barges on the Broadway Bridge over the Willamette River, at Portland, Ore.

continuous girders cannot be classed as truly scientific construction; and the experiment has not since been repeated. However, the bridge did its work satisfactorily for more than two decades, and has only lately been removed so as to make room for a double-track structure.

The Union Bridge and Construction Company when erecting a swing bridge over the Atchafalaya River, where the water was very deep and the current quite swift, employed a neat expedient by setting up the turntable on the pivot pier, erecting thereon the tower, and cantilevering out the trusses, one panel at a time. As the erection was done from a single large barge anchored in the stream, it was necessary to rotate the partially completed superstructure after unbalancing it by a single panel length of steel. In this way it was obligatory to swing the work one hundred and eighty degrees after the erection of each two panels. The

scheme worked to perfection, and the span was completed quickly and without giving any trouble, the barge being moved laterally by the anchor cables as the arms were lengthened.

In *Engineering News* of May 12, 1904, there is described and illustrated a novel expedient for a skew crossing of a canal by running the track through a panel of a truss and depending upon the strength and stiffness of the chord to compensate for the missing diagonal. While the result was apparently satisfactory, the policy of the scheme is doubtful, because a better solution of the problem could have been obtained by the expenditure of more money. It appears, though, that the extra money was not available.

In *Engineering Record,* Vol. 53, p. 712, there is described a temporary wooden drawbridge over the Chicago River, one end being pivoted and the other resting on a scow, which was moved in the arc of a circle to open the draw. A somewhat similar idea is described in *Engineering News,* Vol. 50, p. 372. It consists of a draw span pivoted at one end and supported at the other by a bent resting on rollers running on a curved rail in the bed of the canal, the operation being effected by electric motors.

In *Engineering News,* Vol. 28, p. 441, there is a description of an ingenious way of saving a little money in the construction of a swing span by cantilevering out the ends of the approach spans so as to cheapen the piers, but the author is of the opinion that in most cases the cost of caring for the reversing stresses in the two anchor spans would more than offset the saving in the substructure, unless the pitch of the bed-rock on both sides toward the centre were unusually abrupt—a very rare condition. Another type of bridge, for instance a vertical lift, would have solved the problem much better.

The expedients which follow are some that have been evolved by the author.

In the design of the temporary bridge across the Missouri River at East Omaha, as mentioned in another chapter, the layout was made on a skew of eleven degrees so that later, when the remainder of the permanent construction was being built, all the new piers could be put in and all the new spans could be erected without stopping traffic at all on the old structure, of which only the pivot pier and the swing span were of permanent construction. Ten years afterward it all worked out as it had been arranged for in the beginning.

Another expedient in that structure was, for the sake of economy, to omit temporarily the cantilever brackets for the wagonways and footwalks and to place a single track at the middle of the bridge and operate it and the highway traffic on the same space until business conditions should demand a better arrangement.

The method described in Chapter XLI for righting two of the piers of the permanent construction of the East Omaha Bridge by means of wire ropes with a toggle between was an expedient of value. The author

employed it again a few years afterward for righting the east rest pier of the Sioux City Bridge, which had been moved out of plumb by a land slide that was caused by the piling of a great mass of rock on the bank just under the approach.

The patented arrangement, mentioned elsewhere herein, for building long span bridges at first for single-track, and later by duplicating the trusses alongside and putting in extra lines of stringers to provide for carrying a double-track, is an expedient that, under certain conditions, it may prove advisable to adopt, as it might save the interest over a long term of years on thirty or more per cent of the first cost of constructing a double-track bridge.

The design described in Chapter XL for building a crib and caisson so that it may be sunk part way by the pneumatic process and the remainder by open dredging is an expedient that ought to be very useful in bridging near their mouths some of the rivers that discharge through delta lands into the Gulf of Mexico, and for crossings at other places where similar conditions exist.

In order to anticipate the possibility of a sliding of the banks into the channel of the river and thus overturning or otherwise disturbing the piers of a certain single-track railway bridge, the author designed each of the shore piers as a single cylinder large enough to accommodate the shoes of the trusses, and made the bases of all the channel piers octagonal with the noses of the octagon pointing longitudinally with the bridge so as to cut into the loose sliding earth and turn it aside. He counted upon carrying the piers by open dredging some one hundred and forty feet or more below water, well into a layer of coarse sand that underlay the softer material. His plan was rejected after bids were called for because of its claimed high cost, and ordinary pneumatic piers of timber construction with their long sides up-and-down stream were built and carried down to the safe working limit for compressed air, viz., about one hundred and ten feet below the water level, which was then at or near its extreme height. In spite of vigorous protests by the author, both verbal and written, this policy was adhered to with the result that the anticipated slide occurred before the bridge was completed, and one pier was toppled over to such an extent that it could not be righted. The result was a far greater expenditure of money than would have been necessary to build the substructure properly and safely according to the author's design. This case has been mentioned a second time in order to call attention to the expedient of designing so as to prepare for the contingency of a great lateral earth slide.

At the time it was built, the spread span of the New Westminster Bridge over the Fraser River, shown in Fig. 45*d*, was an expedient, although today it may be considered standard practice, as the idea has been adopted on several important constructions.

The method of semi-cantilevering evolved by the author, as described

in Chapter XXV, was at the time an expedient; but it also has since become standard practice.

The method of anchoring a large, light swing span to its pivot pier by means of a long bolt of great diameter running down into the masonry, as described in Chapter XXIV, is an expedient that ought to be adopted

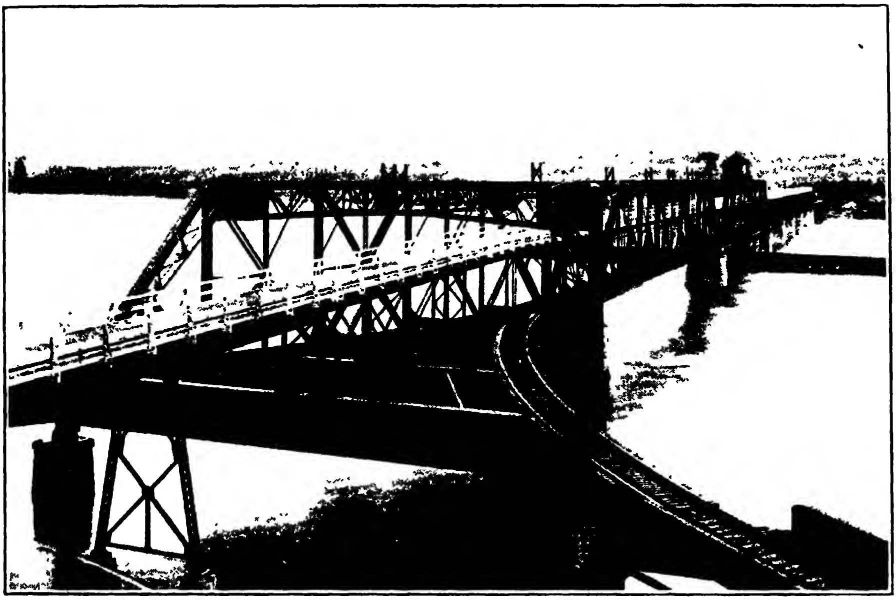

FIG. 45*d*. Spread Span of the New Westminster Bridge over the Fraser River in British Columbia.

wherever the conditions demand the protection that such an anchorage would afford.

In the building of the new Granville Street Bridge at Vancouver, British Columbia, alongside of the old one, which was at a considerably lower level, the two structures were so close together that it was necessary to cantilever one arm of the new swing span over the space occupied by one end of the old draw when it was being rotated—an expedient that worked quite satisfactorily.

In designing the scheme for the erection of the City Waterway Bridge at Tacoma, Washington, on the same line as that of the old bridge, but somewhat higher, it was necessary to maintain traffic. The author accomplished this by building a wooden trestle on the right-hand side of the city end and on the left hand side at the other end, carrying both trestles a little way out into the navigable channel and turning the swing span at a skew so as to connect with the two ends. As the new movable span was to be a vertical lift (see Figs. 31*n* and 31*o*) and a little shorter than the old swing, there was room to put in the new piers for the lift span close in front of the old rest piers of the swing. The old approaches

were then removed and the new ones were built, after which the lift span was constructed aloft on cantilevered falsework tied back to the finished construction; then the falsework was removed, the swing span was floated off, the lift was lowered for traffic, and the old piers were taken out.

In a design for a vertical lift bridge to cross the Second Narrows at Vancouver, British Columbia, in order to carry across it the pipes for the city's water supply, the author evolved an expedient for supporting them at a considerably lower level than the top of the towers, near which they ordinarily would have to go. The proposed structure was designed for a double-track railway between the trusses to carry both steam and electric trains and a roadway and footwalk on each side cantilevered beyond the trusses. He took advantage of this fact by building two shallow, narrow spans to carry the pipes inside and arranged to support them on brackets cantilevered out from the front vertical posts of the tower and braced back diagonally to the rear inclined columns thereof. The movable span at its highest possible position brought the sidewalk flooring within a foot of the pipe girders, the trusses of the said span passing through the rectangular space left between the opposite pipe-supporting spans.

In Bridge No. 9 of the Canadian Northern Pacific Railway across the Thompson River, the water was quite deep and the current swift at the narrow part of the stream, over which it was arranged to build a single through span. As the bottom was covered with large boulders, the author feared that it would be impracticable for the contractor to build, without going to unduly great expense, falsework that would withstand the current; consequently, in preparing the bidding specifications he suggested a means for erection that is worthy to be classed as an expedient. It was to build falsework out from each shore as far as practicable and to place in the intervening space three barges headed up-and-down stream and effectively braced together horizontally at their tops and carrying timber falsework braced substantially in vertical planes, and anchoring the combination diagonally by adjustable cables both above and below so that it could be kept in correct position at all times, even should the elevation of the water vary a foot or two, which was more than would be likely to occur during the erection season. The decks of the barges were to be a little higher above the water than would suffice to put the erected span at its final elevation. The erection was to be done by starting at mid-span and working at a uniform rate of progress in both directions, cantilevering the ends beyond the barge, and letting water into the latter to permit the completed metalwork to come to final position. As it turned out, however, the contractor was able to drive piles between the boulders and to maintain his falsework without going to as much expense as the flotation method would have involved.

The proposed cantilever bridge to cross the entrance channel to Havana Harbor, illustrated in Fig. 52*a*, contains several expedients worthy of mention, notably the spiral approach which the author evolved so as to at-

tain the required elevation in a very limited space. As far as he knows, this is the first occasion that the idea has been suggested for bridge construction. Again, the placing of a large amusement building or casino above the spiral stairway so as to make it the most popular resort in Havana may properly be termed an expedient, for it will utilize at comparatively small expense space that might otherwise have been wasted, the extra cost of the pedestals and columns for carrying the building being comparatively small. The suspension detail adopted for this bridge and which was described in Chapter XXV as having been evolved by the author for the new Quebec Bridge is still an expedient, for it has not yet been actually employed in construction. The hoisting of the suspended span by four wire ropes from barges to a height of nearly two hundred feet clear above the water as projected by the author is also an expedient. But the most unique expedient of them all in this proposed construction is the designing of the metalwork in such a way that, if it be knocked down by gun-fire from an enemy's fleet or by dynamiting, it will not entirely block the navigation of the harbor by its fall. It was necessary for the author to do this in order to overcome the opposition of both the War and the Navy Departments at Washington to the project. How this result was accomplished can be understood by a study of Fig. 45*e*, which shows what would occur were the superstructure cut at different places. This plan was accepted by the General Board of the Navy and by a special board of three Army Engineers appointed by the Secretary of War to investigate the matter. A curious piece of information was obtained during this investigation, which may be worthy of record. One of the members of the Army Board asked whether the shock resulting from the striking of the cut end of the suspended span against the bed of the channel would not cause such a great reaction at the support as to break the metal there and let the span fall entirely. The author assured the Board that it would not; and in order to prove the correctness of his claim, he retained his brother-in-law, A. McL. Hawks, Esq., C.E., to make some experiments by dropping one end of a cast iron bar suspended at the other end from a large spring scale, and recording the readings of the scale, the ratio of length of bar to fall being the same as that of the length of span to its height above the channel bed. Much to the surprise of all those interested in making the experiment, the reading reduced immediately to nearly zero and then went for an instant to nearly the total weight of the beam and finally to about one half of the said weight. The apparatus was crude and the readings were not well recorded; but the experiment was repeated a number of times with approximately the same results. Had the apparatus been perfect, it is likely that it would have shown a zero reading during the fall, one of double the static reading of the suspended beam immediately after the shock, and that found by applying the law of the lever after the bar had come to rest. Based upon this experiment, the author reported to both Boards

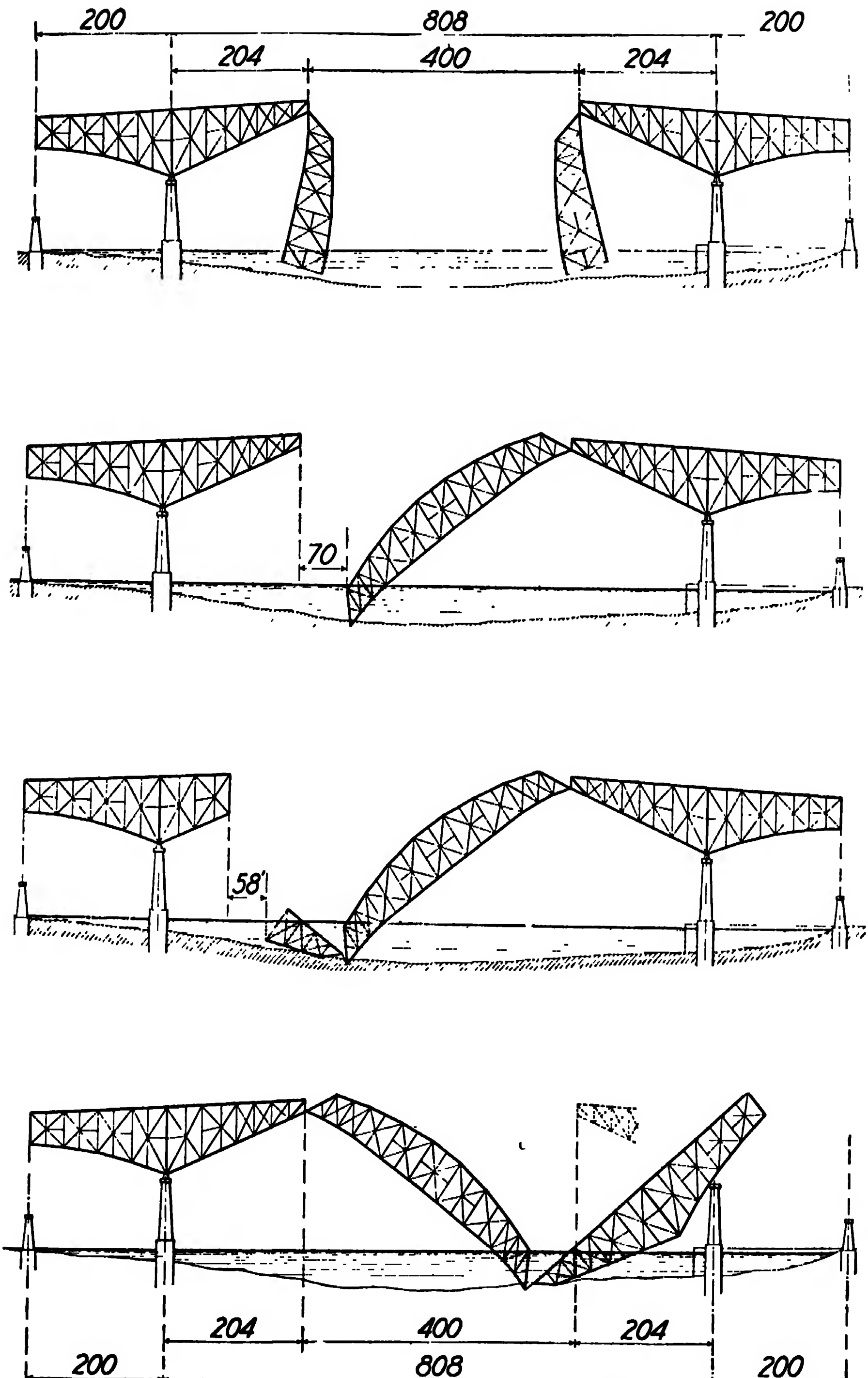

FIG. 45e. Methods of Failure of the Proposed Havana Harbor Bridge if Struck by Gun-fire.

that the worst possible result of the shock would be to double the dead load reaction at the support, making it about the same as the greatest reaction there from combined dead load, live load, and impact, and showing conclusively that the effect of the jar could not possibly bring down the other end of the span. Meanwhile, however, the Army Board had reported favorably on the author's plan submitted, having accepted his assurance that the support would carry safely the dead load under the most adverse circumstances; but the confirmation offered by the experiment was most satisfactory to all concerned.

The author's latest expedient is one evolved in connection with the Ohio Avenue Bridge over the Kaw River in Kansas City, Kans., which

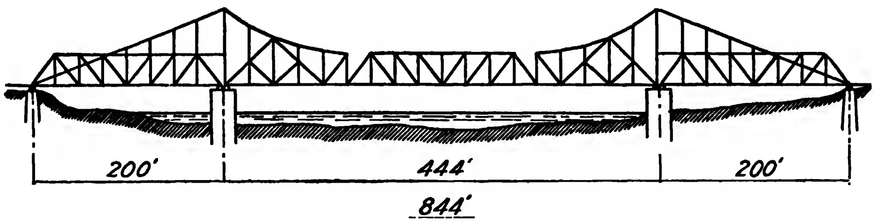

FIG. 45f. Simple Span Bridge Converted into a Cantilever Structure.

structure was most unjustly condemned by the Drainage Board as being an obstruction to the flow of the current. It consists of three riveted spans, one of which was previously described herein and illustrated partially in Fig. 1h. These spans are in excellent condition; but, owing to strong pressure brought to bear on the railroad company by numerous business patrons who have been induced to believe in the erroneous statements of the Drainage Board, that company has agreed to remove and possibly to replace its structure. To do this to best advantage the author suggested the utilization of all three of the old spans by converting the bridge into a cantilever structure, as shown in Fig. 45f, lengthening it from six hundred feet to eight hundred and forty-four feet in order to conform to the increased width of river established by the Drainage Board and to the increased skew, the existing structure crossing at an angle of about twenty degrees and the new one at about twenty-seven degrees. The increase was adopted in order that the sharpest allowable curve (fifteen degrees) on the west embankment might not encroach on the right-of-way of another railroad. The tops of the main posts of the cantilever arms are to be tied back to the end pins of the anchor arms by means of eyebars; and suitable anchorages will have to be built to take care of the uplifts that these backstays produce. The only members of the anchor arms that will have to be modified to meet the new conditions of stress are the bottom chords, which will have to take compression from end to end, and also, in certain panels, alternating compression and tension.

The author had figured on employing Mayarí steel, or some other alloy of like capacity, for the principal members of the cantilever arms in order to reduce the uplifts as much as practicable, and the same alloy in the new members of the bottom chords of the anchor arms so as to avoid the adoption of unduly large sectional areas. The excess price quoted for the finished Mayarí steel work was only eight-tenths of a cent per pound as compared with carbon steelwork. The estimated cost of the repaired bridge is about sixty per cent of that of a new structure of the same carrying capacity.

ADDENDUM

After the plans for this reconstruction were partially completed, it was found necessary to abandon the scheme, because of excessively high property damages that were claimed by the land owners whose holdings would have been crossed by the new line.

CHAPTER XLVI

DATA REQUIRED FOR DESIGNING BRIDGES, TRESTLES, AND VIADUCTS

THE importance of a thorough preliminary study of all the conditions that can possibly affect the designing of a structure cannot well be over-estimated. Too often designs are made from insufficient data, with the result that changes in plans become necessary as the work progresses; and such changes are very expensive in many ways.

First. They cause delay—and time is money.

Second. They involve the discarding of work already done, and that work costs money.

Third. Modifications in construction are costly, *per se*, for remodeling is slow and expensive work.

Fourth. Notwithstanding the fact that the specifications and contract usually provide for the contingency of making changes and determine upon a method of payment for them, nevertheless it is true that alterations of every kind are nearly always a source of unusually large profit to the contractor. One reason for this is that changes are a legitimate excuse for delay, and as the company is generally in a hurry for its structure the contractor has to be persuaded to make special effort to hasten completion. The most common means of persuasion is offering additional compensation.

Fifth. The making of important changes in the plans is a good and sufficient reason for either extending the time set for completion or for cancelling entirely the clause in the contract relating to that subject. In dealing with the contractor concerning modifications in plans and construction, it is always best to have made and signed a supplementary contract covering in detail not only the changes themselves but also the extent to which they shall affect the time of completion of structure.

Sixth. But, worst of all, it is held by many lawyers that any fundamental change in the work will render the bond null and void; consequently, if this view be correct, in case that the contractor throws up the contract the company will have no redress, but will have to take his plant, pay all of his outstanding bills for labor and materials, and complete the construction by either administration or the letting of a new contract. In effecting a final settlement with the contractor by legal process the fact that changes in the construction were made by the company will generally militate heavily against the latter, especially if the trial be by jury—that relic of barbarism which enlightened nations seem unable to cast aside.

In view of all these objections to changes being made in plans after the contract is let, is it not evident that any money spent legitimately upon the preliminary investigations is money well expended? Nevertheless, one of the most difficult tasks that the consulting engineer encounters is the persuading of his clients to provide the necessary money for such preliminary investigations. Under ordinary conditions one should be able to prove convincingly the necessity of making sufficient borings to determine beyond the peradventure of a doubt the location of bed-rock and the character of the overlying soil, or the desirability of surveys or other investigations to find the greatest volume of water that will pass the cross-section in a given time; but when it comes to unusual conditions, such as the inception of work of a novel character, it is hard to persuade the promoter that it is advisable to spend money to learn how best to design and construct the work, for he thinks that the engineer ought to know such things without investigating; and it is not unusual for a promoter to remark to the consulting engineer, "I am paying you a big fee for your special knowledge, and, in addition, you want me to spend a lot of money to teach you things that you ought to know but don't." On one occasion the author nearly lost the engineering on some four million dollars' worth of elevated railroad work by requesting permission from the President to spend three or four thousand dollars on some special studies and estimates. The result of the expenditure, however, was the immediate saving of more than one hundred and fifty thousand dollars.

In order to facilitate the professional work of his firm the author some years ago prepared a little pamphlet for distribution to clients and to those who request information concerning the cost of bridges. It is entitled "List of Data Required for the Proper Designing of Railroad Bridges and Trestles," and is reproduced here *verbatim*, including the prefatory remarks.

"The following lists of data required to make the best and most economic designs for railway bridges and other structures have been prepared by us to submit to our clients in various countries, spaces being left for writing in the information. For any particular crossing, of course, it is not necessary to collect all the data called for on the list; but the more preliminary information concerning the conditions that is secured, the more perfect and economical will be the design made.

"The objection is sometimes raised that the collection of so much information is expensive. It certainly is; nevertheless it is in every way compatible with true economy.

"The collection of the data can either be done by the railroad company through its engineers, or it can be entrusted entirely to the bridge specialist who is to prepare the plans and specifications. For large bridges and for a group of small ones it is best to let the specialist do this preliminary work; but for a small bridge or two only, it will generally be advisable on the score of economy to have the railroad engineers collect the data.

"BRIDGES

"1st. Profile of crossing on which should be located the following: (Elevations can be written in below, calling the elevation of base of rail at mid-length one thousand.)

a. High water mark (extreme)...

b. Low water mark (extreme) ....
....
c. Bottom of channel or mud line ....
....
d. Bed-rock, if any, with overlying strata. (Describe fully the soil, and give approximately its bearing capacity) ....
....
....
....
....
e. Grade line on structure, *i. e.*, the elevations of base of rail. If structure is to be on curve, indicate the compensation, if any ....
....
....
f. Kinds of approaches, whether of steel viaduct, earth embankment, or timber trestle ....
....

Profile should be made to scale, and the scale of drawing should be indicated thereon.

2nd. Any restrictions that there may be concerning the following:

a. Location of piers ....
....
....
b. Lengths of spans ....
....
....
c. Overhead clearance beneath structure ....
....
....
d. Shore protection ....
....
....
....
e. Channel booms or guides ....
....
....
....

Clearance between trusses, number of tracks structure is to carry, distance from centre to centre of same, and gauge of railroad ....
....
....

Vertical clearance above base of rail, also horizontal clearances near the deck...
....

5th. Style of floor, whether of timber ties, ballast, or solid steel. Is the structure to provide for highway traffic; and, if so, of what kinds? How many lines of stringers per track are to be adopted? Make sketch of floor, and give sections, locations, and heights of track rails and guard rails. State whether snow plows are used on the road. Is the floor timber to be creosoted or otherwise treated?
....
....
....
....
....

6th. Widths of sidewalks, if any are required

7th. Live loads for spans.

  a. Maximum weight of engine and tender; make sketch showing wheel spacing and load on each axle, or else adopt some standard loading.

  b. Maximum weight of cars fully loaded and wheel base of the same; also weight per foot of loaded cars

  c. Highway live loads, if any. (Preferably adopt one or more of those given in some standard specification)

8th. State whether stream is navigable, and, if so, what clear height will be required beneath structure; also what clear distances will be required between piers?

9th. Is stream subject to sudden rises and rapid currents, and at what seasons of the year?

10th. Does stream carry much drift?

11th. Is there any danger of the channel changing? State fully the liability to scour

12th. State the cost in U. S. gold dollars of the following delivered at bridge site:

  a. Portland cement, per bbl

  b. Broken stone and gravel, per cu. yd

  c. First-class masonry stone, per cu. yd

  d. Sand (clean, sharp, and coarse), per cu. yd

  e. Transferring steel work from cars or vessel to bridge site, per lb

  f. Timber for flooring, per M. ft. B. M

  g. Timber for falsework, per M. ft. B. M.

  h. Piles for falsework, per lin. ft

  i. Labor per day

  j. Treatment of timber, per M. ft. B. M.

13th. Map showing location of bridge, including stream for at least half a mile each way from bridge site. (For unimportant streams and those not navigable this will not be required.) Give scale of map

14th. Is structure on tangent or curve? If on curve, give degree of curvature, or angles of skew, and show same on map. Is curve to be cased? Show beginning and end of curve. . . . .

. . . .

. . . .

15th. Is structure square or on a skew? If the latter, give angle of skew and make a sketch. . . . .

16th. Area drained by opening, if it has been measured or estimated, together with such a description of the watershed as will enable one to determine what constants to use in the formulæ for flow. Instead of this may be given the measured or estimated cross-section and velocities of stream at high water. . . . .

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17th. When the stream is navigable and a low bridge is required, some style of movable span must be used; hence, to aid in selecting the proper type of structure, please answer the following:

- **a.** Will a centre pivot pier be permissible, and, if so, what clearances will be required between it and the two end piers? . . . .

  . . . .

  . . . .

- **b.** If a centre pivot pier cannot be used, what clear waterway will be required between end piers of lift-bridge, measuring at right angles to the direction of the channel? . . . .

  . . . .

- **c.** What clear height will be required beneath structure for the passage of vessels? . . . .

  . . . .

- **d.** State minimum time in which it will be necessary to open draw span or raise lift span to full height. . . . .

  . . . .

- **e.** Will electricity for operating the span be obtainable from any existing plants at a reasonable price? . . . .

  . . . .

- **f.** About what would be the probable maximum number of times the span would have to be opened or raised in 24 hours? . . . .

  . . . .

- **g.** Dock lines should be indicated clearly on both the plan and the profile, also the exact angles they make with the centre line of bridge and with the centre line of clear channel required. . . . .

  . . . .

  . . . .

18th. Any other data not herein mentioned, which may prove useful in making the design. . . . .

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. . . .

. . . .

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. . . .

. . . .

"STEEL RAILWAY TRESTLES, VIADUCTS, AND ELEVATED RAILROADS

1st. Profile on centre line of structure, on which should be indicated the following: (Elevations can be written in below, calling the elevation of base of rail at mid-length one thousand.)

a. Ground line..

....

b. Bed-rock, if any, with overlying strata. (Describe fully the soil and give approximately its bearing capacity)........................

....

....

....

c. Grade line on structure or required elevations of base of rail. If structure is to be on curve, indicate the compensation, if any............

....

....

d. Kinds of approaches...

....

e. Cross-sections of ground every 30 feet or 40 feet, extending at least 30 feet on each side of centre line of structure, and, on irregular ground, a contour map with horizontal sections from two (2) to five (5) feet apart vertically..

....

....

....

f. High water mark, if any...

....

Profile should be made to scale, and the scale of drawing should be indicated thereon.

2nd. Any restrictions that there may be concerning the following:

a. Location of pedestals and abutments.....................................

....

....

b. Lengths of spans..

....

....

c. Overhead clearance beneath structure....................................

....

....

d. May longitudinal bracing be used, and, if so, with what restrictions?....

....

e. Is it permissible to carry the transverse sway-bracing to the ground, or must an unobstructed space be left longitudinally beneath the structure?

....

3d. Number and spacing of tracks and gauge of railroad. State whether structure is to carry also highway traffic, and, if so, what kinds......................

....

....

....

4th. Style of floor, whether of timber, reinforced concrete, buckled plate, or asphaltum and concrete on buckled plate. Make sketch of floor................

....

....

5th. Widths of sidewalks, if any be required..................................

....

6th. Live load. (See Bridges.)

7th. State fully the cost in U. S. gold dollars of the following at site: (See Bridges.)

8th. Plan of crossing showing degrees of curvature, if any, angles of skew, easements, points of curve, etc.

9th. If in a city or town, show streets, alleys, building lines, curbs, etc., crossed or affected in any way by the structure; and show where columns are to be located, whether in street or on sidewalks near curbs, giving exact locations for all special cases..

....

....

10th. If any tracks or other obstacles are to be spanned, locate them exactly and give clearances required, both vertical and horizontal..........................

....

....

11th. Indicate on profile and plan where steel trestle is to begin and end...........

....

....

12th. Any other data not herein mentioned, which may prove useful in making the design"...

....

....

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Captious readers of this chapter may make the comment that the preceding lists are altogether too detailed for the purpose of designing bridges, for while such minor matters as the cost of cement, sand, gravel, stone, hauling, etc., would certainly affect the total cost of a structure, they cannot influence its design. To such readers the author would state that in certain cases even such a small thing as the cost per barrel of cement at site would change the layout of spans from that which would ordinarily be adopted. For instance, in one of his bridges the cement at site was worth eighteen dollars per barrel. Is it not evident that for such a location the quantity of concrete used should be reduced to a minimum and that cut stone masonry should be adopted instead? Again, in building bridges in mountainous districts, the metal work for the superstructure has sometimes had to be carried or dragged from the railroad or seaport by burros. Would not this circumstance affect greatly the designing of the individual members of the superstructure? In collecting data for the designing of bridges no condition is too trivial or too unimportant to be worthy of noting, and the important conditions should always be investigated with the utmost thoroughness, regardless of how much the investigation may cost.

CHAPTER XLVII

LOCATING OF BRIDGES AND PRELIMINARY SURVEYS

For small bridges and culverts, the location is determined by the alignment of the road. Usually this is fixed by conditions which are beyond the influence of the needs of the smaller crossings; and hence it governs their location largely, if not entirely. But where the crossing is of sufficient magnitude and importance to influence the location of the line, a careful study of the physical conditions by a reconnaissance covering a number of possible sites should be made, in order to secure the best and most economical crossing possible. That layout should be selected which is the best in respect to the following particulars:

1. Permanency of channel.
2. Narrowness of channel.
3. Large average depth of water relative to the maximum depth.
4. Straight reach of river for several miles. especially if draw-spans are contemplated in the layout.
5. Freedom from islands or other obstructions that might disturb or deflect the current.
6. Remoteness from sharp bends.
7. Presence of high banks.
8. Possibility of crossing at right angles to axis of stream.
9. Absence of curves in both approaches to the bridge or upon the structure itself.
10. Absence of sag in grade on structure.
11. Economy, which involves the following considerations, in addition to those already given,
    - *a.* Depths of pier foundations.
    - *b.* Materials to be excavated for substructure.
    - *c.* Quality of the foundation material.
    - *d.* Force of current during high water.
    - *e.* Height of piers.
    - *f.* Cost of protection work and of its maintenance.

One of the most important features affecting the layout of a bridge is the permanency of channel. With a shifting channel a longer bridge must be provided to meet the vagaries of the river, and sometimes it is necessary to construct two draw spans in order to meet navigation requirements. Examples of this case are the author's bridges over the Missouri River at Sioux City and East Omaha. A better appreciation

of the conditions which promote permanency of channel will follow from the study of the general action of rivers. This is essentially a consideration of the continuous readjustment between two contending factors in an effort to bring about an equilibrium—the water seeking a lower level and the resistance set up by the soil tending to retard its motion. A river receives the run-off from a definite, fixed drainage basin. This run-off in seeking a lower level follows the line of steepest declivity, and usually sets up such a velocity that scour results. The softer the material forming the channel, the more readily will scour occur. This scouring action forms bends in the channel which become accentuated until sufficient additional length has been introduced to decrease the slope to such an extent that the resulting velocity will no longer produce scour. The stream has then attained, for the time being, a condition of equilibrium or fixed regimen for a particular rate of discharge during which neither scouring nor silting takes place. It has been found from observations made on the rivers of India that for any section of channel and character of silt the critical velocity (at which neither scouring nor silting takes place) depends upon the depth and is given by the equation,

$$v_s = md^{0.61},$$

where v_s = the critical velocity in feet per second,
d = depth of channel in feet,
and m = a coefficient having values as follows:

Light sandy silt........................	0.82
Coarser but light sandy silt.............	0.90
Sandy loam..........................	0.99
Coarse silt, such as débris of hard soils....	1.07

But the run-off from the catchment area varies from time to time and a new velocity is produced, disturbing the pre-existing regimen; and then scouring or silting results until another approach is made toward equilibrium. The river, as a matter of fact, is in a constant state of readjustment, oscillating back and forth between a preponderance of scouring and of silting. It is true that these two actions go on simultaneously in different parts of the river, owing to whirls and cross currents. For example, the concave sides of the bends are being eroded, while the convex sides are being filled. Unless the banks of the stream are sufficiently stable to resist this scouring action, no permanency of channel can be expected without resorting to protection. In case of rivers the channels of which lie in flood plains of alluvial deposits flanked by bluffs of hard and more stable formations, such as the Missouri for example, the tendency is for the stream to oscillate from bluff to bluff, forming a series of bends, which exhibit a general, progressive shifting of channel location down the valley. Without protection works sufficient to fix the channel, it is a foregone conclusion that any bridge location on such a stream will sooner or later be menaced by this progressive down-stream movement.

With this brief exposition of general conditions affecting permanency, there will now be considered what specific things indicate a relative stability of channel. Hard bottom underlying the silt, banks of gravel, and hard clay, shale, and limestone formations involve favorable conditions. Sections having comparatively large ratios of area to wetted perimeter are favorable for permanency. A straight reach of the river is an indication of relative stability, because the banks escape the direct impact of the current, and there is, in consequence, less danger of erosion.

Having given proper weight to the relative permanency of the channel, the other conditions affecting the location of a bridge site are next to be considered.

Narrowness of stream is an advantage, as a shorter bridge will be required.

The benefit of a large average depth as compared with the maximum depth is that such a condition involves a more efficient discharge section and less liability to scour in flood time than will exist when the ratio of the said depths is small.

When draw-spans are contemplated, a straight reach of the river is necessary so as to provide sufficient room for permitting a boat and its tow to straighten out and to direct themselves squarely toward the channel span before approaching dangerously near the bridge.

Freedom from obstructions in the stream, such as islands above the bridge site, is desirable, because such obstructions deflect the current shoreward and increase the possibilities of an erosion that might permit the river to cut in behind the bridge.

Remoteness from sharp bends, especially above the bridge site, is advantageous, because the erosive action of the current at such bends, receiving as they do the full impact of the water, is excessive. There is always in rivers with alluvial flood plains the danger that the current will cut in behind the bridge, unless effective protection work is installed. The soundness of this statement is well illustrated by the difficulty that has been experienced in protecting the railroad bridge across the Missouri River near Blair, Nebraska. That structure is located about one mile below a sharp, right-angled bend in the river, which bend, in turn, is only two miles down stream from a still sharper bend in the reverse direction. The river has repeatedly tried to cut across and has been prevented from so doing only by extensive bank protection. An illustrated description of this protection work is given in the *Engineering Record* for March 2, 1912. Both bends had to be revetted on the concave side to hold the river in check. Since 1882, when the bridgework was started, over $1,425,000 have been spent in protection for this structure, an average of $44,530 per annum.

The presence of high banks is desirable, as they reduce the cost of the approaches and also better confine the floods to the main channel.

It is always best to cross the stream as nearly at right angles as pos-

sible. Any departure from a right-angled crossing means a longer bridge and also skewed spans and longer piers, all of which features involve increased expense. In most cases, especially when the current is swift or the river is navigable, the piers should be set parallel to the direction of flow in the main channel, as they will then present less obstruction to the stream and to navigation, and as they will receive less pressure from the impinging water and will catch less drift.

If possible, the bridge should be so located, or the line should be so shifted, that the structure will be approached on tangents and not on curves. This will afford the trainmen the opportunity to see if the track is clear before reaching the structure, and will reduce the danger of derailment thereon to a minimum.

Another condition to be avoided is the location of a bridge at a sag in the grade, for such a sag would produce a change in direction of the moving mass as the train comes on, and would thus cause an increased load effect upon the structure. Also, it gives to the bridge an objectionable appearance.

The restrictions previously given and others established by the War Department (see Chapter L) will affect the economy of the structure.

In any event it will be necessary to determine the actual physical conditions by a preliminary survey. An alignment map and profile of the road for the crossing and for some distance on each side thereof should be obtained from the Railroad Company. If not obtainable, a preliminary survey should include the collection of that information. From such a map and profile it can readily be seen whether any modification in grade or alignment could advantageously be made.

If such modifications in the road can be effected, a stadia survey of the stream meanders should be made, tying it in with the former bridge location and covering such a stretch of the river as a reconnaissance shows to be desirable. This information when plotted in conjunction with the previous alignment will show whether a better bridge site is obtainable than the one first contemplated. In making a selection of a site, due regard must be paid to the cost of modifying the alignment of track as well as to the previously enumerated conditions for best bridge location. A selection having been made, the profile of the crossing can be run and soundings taken above and below it so as to show the topography of the stream-bed. At each end thereof the profile of the crossing should extend well back from the stream so as to include the entire space between extreme flood lines. With these data and with borings showing the material of the river bed and of the strata below, a tentative layout of structure may be made and the sufficiency of waterway tested, as per the directions given in Chapter XLIX. This preliminary survey should also include elevations and positions of high-water marks along the reach of the river considered; it should develop evidence of scour, if any; and it should determine the nature of the material composing the stream-

banks and flood plain, the character of the vegetation, the kinds and quality of the timber, the proportion of cleared or cultivated land, and the location of buildings and fence lines.

To decide upon the very best of several possible bridge locations, it is often necessary to make a number of complete estimates of cost not only of the bridge itself and its approaches, but also of the road for quite a distance from each end of the structure and extending to points that are common to all the layouts under comparison. Generally speaking, the least expensive of these is the one to adopt; but sometimes there are differences in the profile elevations which are of sufficient importance to influence the final choice of location by bringing into consideration the cost of operation and maintenance. A good bridge engineer will never permit himself to economize on time, labor, or expense when endeavoring to determine the economics of such an important problem as the best possible location for a costly structure.

CHAPTER XLVIII

BORINGS

Before a layout for a bridge can be projected, it is necessary to know the kind and the depth of the materials available for substructure foundations, and to obtain like information concerning those which must be passed through in order to reach the said foundations. To secure all these desired data some sort of underground exploration must be undertaken. The usual method is to make borings of some kind or other; and the correct interpretation of these is an important matter, especially in the case of large and costly structures. It would be advisable for the engineer having this responsibility to fortify his judgment by consulting records of other borings, wells, and test-pits made in the vicinity of the bridge site, and to secure from authentic published reports all available information concerning the geological formations in that general locality. These reports, especially those published by the Government, can usually be found in any of the large public libraries. The presence of glacial drift is apt to mislead one, if he be not forewarned of its existence. Such drift may be expected in any of the streams in North America situated to the north of the Ohio River and to the east of the Missouri. Below the alluvial deposits in a river bed of this district will be found the glacial drift of sand, gravel, clay, and boulders mixed in a heterogeneous mass. Often in past ages the water in its percolation has been impregnated with sufficient lime to cause a cementing effect on the gravel; and a layer of material thus consolidated presents considerable resistance to the drill point. Also the striking of a large boulder is misleading; and when this happens one is apt to draw the conclusion that a solid-rock ledge has been encountered. Hence the need for collateral evidence.

Several different methods for making borings have been developed, each one having some advantage for particular conditions. The simplest one is that of using an auger welded to a piece of pipe, to which other pieces can be screwed as needed. This auger is rotated by hand and withdrawn from the hole from time to time, bringing up a sample of the material for inspection. Such samples, together with their depths and the difficulty experienced in penetrating the material, must be the basis for the engineer's conclusion. This method is specially suitable for clayey soils.

Another method is that known as "wash borings." In this the material is broken up by a churn drill working inside of a pipe, and floated

to the surface by means of a strong jet of water issuing from the drill point while it is at the bottom of the hole. This flow of water is supplied by a force pump and is transmitted to the drill point through the small pipe to which the said drill point is attached. From these washings, their depths, and the "feel of the drill," the engineer must form an opinion as to the kind of material passed through and its bearing capacity so as to decide upon where to rest the piers. This method is available for silt, sand, clay soils, shale, and, to a limited extent, rock.

Another method of underground exploration is that of "core drilling." In this the drill is constructed so that its rotation cuts out a cylindrical core extending upward inside the drill point and into the space within the churning pipe. This core is broken off at various times and brought to the surface, then it is taken out of the pipe and kept for future inspection and testing. This method permits of the engineer's seeing the various materials as they actually occur and in large enough pieces to judge of their characteristics and to make tests upon them, if so desired. It gives positive results and is best suited for the harder shales, sandstones, limestones, and granite formations. The overlying softer materials are usually penetrated by the wash boring process before the core drill is started.

After a hard stratum is discovered, it is desirable to penetrate it several feet so as to make sure that it has the requisite thickness for distributing the load from the pier, and that it is not merely a boulder. In limestone and sandstone formations there is always the possibility of striking subterranean caverns or overhanging cliffs due to former erosions in the earlier geological periods. To develop the presence or the absence of such underground caverns or cliffs, the drill should be shifted several feet sideways and another hole put down. A single boring at a pier site is not altogether conclusive. The author has often put down four holes for a single pier, one at each corner, but generally one hole per pier will suffice—or less for a wide crossing, if the conditions of the river bed be very uniform in respect to character of materials.

The equipment needed for making wash-borings consists of a two and a half inch pipe for casing and a one inch pipe for drill rod, both cut into eight-foot lengths for convenience in handling; several different kinds of drill points; a three-legged derrick or tripod with a pulley attached at the top for passing the rope that operates the drill; and a pump with a small hose to connect with the drill rod so as to supply the water needed for bringing the washings to the top of the casing. At the lower end of the rod a drill point is attached. The best drill point for all-around work has two cutting edges arranged in the shape of a cross. These crossed edges of the bit break any pebbles that come into the hole and do not allow them to ascend with the water and to jam the drill pipe against the casing. This drill point has holes in the sides from which the water flows, as, in fact, do most of the other types of drill points em-

ployed. The drill rod is churned up and down while water is being pumped through it. At the same time a twisting motion is given to it by the attendant, and in this way a fairly round hole is obtained. As the drill advances, the casing is driven down so as to keep close to the position of the point and thus prevent the caving in of the sides of the hole; for such caving would cause a packing of soft sandy material around the drill and would bind it fast. A satisfactory hammer for this purpose can be made of a length of pipe with a drive-head screwed on the bottom. This ram should be handled by men direct without tackle in order to obtain the full force of the blow. When the washings in the overflow from the top of the casing change in character, the drill is stopped and a measurement made of the depth of drill point. This is readily ascertained by counting the number of pieces of pipe, which should, preferably, be of uniform length. A record of this depth and a description of the material encountered should be made at the time by the responsible head of the party. Drilling is then resumed, and the operations are repeated until the desired stratum is reached or a sufficient depth attained that will ensure the necessary bearing resistance. It is desirable to drive the casing frequently so that the surrounding soil will have less opportunity to pack about it and develop too much skin friction.

Before sending out a party to make borings a full outfit of tools and equipment should be shipped to the site. Many of the tools are special ones; hence the party should not rely upon purchasing any of the outfit, excepting perhaps pipe, from some market convenient to the site.

The following is a complete list of the tools and equipment required:

1 double-acting horizontal force pump, Fairbanks-Morse & Co. Catalogue No. 60, page 329, Fig. 834, No. 12 brass-lined discharge fitted for 1 in. hose.

2 pieces of four-ply 1 in. rubber hose, each 50 ft. long, with iron couplings for 1 in. pipe attached.

15 ft. of 2 in. suction hose with globe strainer attached.

1 Water swivel for 1 in. pipe (Crane Co. Catalogue, Fig. 404, page 88). See sketch in catalogue.

2 Pipe cutters (No. 2 and No. 3, F. M. & Co. Catalogue No. 60, Fig. 765, page 508) with 3 extra cutter wheels for each cutter.

1 Pipe vise, hinged, size No. 2, F. M. & Co. Catalogue No. 60, Fig. 782, page 518. Stocks and dies for threading 1 in. and 2½ in. pipe. This will require two sets of stocks and dies, page 505–506, F. M. & Co. Catalogue.

2 Trimo wrenches, 18 in., F. M. & Co. Catalogue No. 50, Fig. 775, page 514.

2 Vulcan chain wrenches No. 13, F. M. & Co. Catalogue No. 50, Fig. 778, page 516.

1 Pipe lifting clevice, F. M. & Co. Catalogue No. 50, Fig. 103, page 531.

1 Lifting tongs No. 2, F. M. & Co. Catalogue No. 50, Fig. 109, page 516.

1 Pipe puller and dies, No. 3 with 2½ in. dies, F. M. & Co. Catalogue No. 60, Fig. 115, page 531.

2 Jack screws, 14 in., ten ton capacity, F. M. & Co. Catalogue No. 60, Fig. 115, page 463.

12 ft., ⅞ in. chain to use in pulling pipe with levers.

2 Single blocks, 4¾ in. sheaves, F. M. & Co. Catalogue No. 60, Fig. 917, page 533.

1 Single block, 4¾ in. sheave, F. M. & Co. Catalogue No. 60, Fig. 798, page 533.

1 Double block, 4¾ in. sheave, F. M. & Co. Catalogue No. 60, Fig. 799, page 533.

100 ft., ¾ in. manila rope.

1 Hand hammer No. 1.

1 Sledge hammer No. 12.

1 Hand saw (cross-cut).

1 Monkey wrench.

1 Pocket alligator wrench, F. M. & Co. Catalogue No. 60, Fig. 786, page 515.

1 Brace and ¾ in. bit.

1 Hand axe.

1 Chopping axe.

1 Screw driver, 6 in.

1 Triangular file, 12 in., F. M. & Co. Catalogue No. 60, Fig. 861, page 520.

1 Mill bastard file, 12 in., F. M. & Co. Catalogue No. 60, Fig. 854, page 520.

2 Steel hand chisels.

1 Caulking iron for caulking barges.

1 Oil can and oil.

3 2½ in. drill bits, F. M. & Co. Catalogue No. 60, Fig. 615, page 354.

1 2 in. expansion bit, F. M. & Co. Catalogue No. 60, Fig. 610, page 354.

1 Taper tap for 1 in. pipe, F. M. & Co. Catalogue No. 60, Fig. 626, page 354.

4 Drive heads for 2½ in. pipe, F. M. & Co. Catalogue No. 60, Fig. 94, page 352.

2 Forged steel shoes for 2½ in. pipe, F. M. & Co. Catalogue No. 60, Fig. 421, page 353.

3 Drive rings. These will have to be manufactured specially in a machine shop.

½ dozen 1 in. elbows.

1 2½ in. tee.

½ dozen hydraulic recessed couplings.

$2\frac{1}{2}$ in. pipe in 8-ft. lengths, as much as required.

1 in. pipe in 8-ft. lengths, as much as required.

Hydraulic couplings (extra long—not recessed) for both sizes of pipes as required.

1 lb. red sheet packing for pump and swivel.

$\frac{1}{2}$ dozen balls of candle wick for packing pump, etc.

1 50 ft. tape.

1 Note-book.

1 two horse-power gasoline engine, where it is decided to use engine power instead of man power to operate pump and drill.

Some extra pipe for casing is desirable, because it is not always possible, before moving away from a hole, to pull the entire casing pipe used for a deep boring. Ordinarily a two and a half inch pipe is sufficiently large for the casing, but in deep borings a three-inch one may be used to better advantage. Also where a long portion of the casing is exposed to a strong current a three-inch or even a larger pipe will be better than one of the smaller diameter. For deep borings the pump should be double acting, as a strong, continuous flow of water is needed to bring the particles to the surface; and in some cases it will pay to use a gasoline engine for pumping instead of the usual man-power.

When borings have to be made in a stream where the current is too deep or swift for temporary staging, it will be best to use two small scows each about ten by twenty feet. These can be placed alongside and separated a few feet from each other so as to leave an opening for the drill between. This clearance is needed to prevent the swaying and tilting of the barges from bending or breaking the pipe. Timbers are laid across the opening and firmly fastened to the boats so that they will act as a unit. This arrangement is desirable for equalizing the pressure when pulling casings. On this platform over the centre of the space between the boats is erected an A derrick frame, from which the drill is operated. To secure the boats in position, it will be necessary to tie to some existing structure or to put out a couple of anchors upstream. These anchors can readily be made by filling boxes with rock or concrete and tying fast to them before dumping in the water. For river work it will take about 500 feet of $\frac{7}{8}''$ rope to connect the boats to the anchors. A buoy, made of a block of light wood, should be fastened to each anchor by a rope of sufficient length to permit it to float on the surface. It will prove of value, if the anchors become snagged and have to be tripped.

The derrick may be built from four pieces of timber, each $2'' \times 6'' \times 20'$ and braced with $2'' \times 4''$ planks. Two platforms should be constructed, one about seven feet from the base and the second six and a half feet above the first. This will facilitate the driving of the casing.

Where very fine sand or quicksand is encountered, it becomes a difficult matter to drive the pipe without breaking the couplings. A case of this kind occurred in making the borings for a bridge across the At-

chafalaya River. A special method, used successfully on that and on one other occasion by the author's men, was to drive a four-inch pipe about six feet into the material below the bed of the river and let the top of it extend three or four feet above the water surface, a tee connection being screwed thereto. Two barrels were employed to hold a thin clay puddle, which was pumped through the drill pipe instead of the usual clear water. As this puddle overflowed from the top of the four-inch pipe it was returned to the barrels and used over again. The clay made the sand hold together, so that a depth of over 130 feet was attained by this process in less than five hours.

Should the casing become gripped in the material penetrated and all efforts to pull it prove futile, a portion of it can be saved by lowering a stick of dynamite to a coupling about 20 feet below the bed of the river. The explosion thereof will break the coupling so that the upper portion of pipe can then be pulled and used over again. Should boulders be encountered near the bed of the river, it is best to move the drill four or five feet away and start a new hole; however, should there happen to be a bed of boulders, it may be necessary to break up the obstructing boulder with a charge of dynamite. Before placing the explosive the casing should be withdrawn three or four feet in order to avoid its being injured. After the boulder is shattered, the casing pipe can be driven, provided the expansion bit is used to enlarge the hole.

The equipment needed for the core-drilling process is similar in many respects to that for wash borings. An outside casing is used, which casing is driven to bed-rock and washed clean inside by means of a water-jet before the core-drill is started. The core-drill bit is a ring, provided in one type with black diamonds for the cutting agent, and in another type with chilled steel shot. The bit in either case is rotated by means of the hollow rods to which it is attached and through which a stream of water is kept flowing, except when going through clay or soft shale. A core barrel some ten feet long is provided above the bit. With the steel-shot type no attempt is made to wash the cuttings to the top, because the required flow of water is so great as to disturb the shot. The cuttings are carried into the core chamber and brought to the surface when the core is lifted. With the diamond bit a strong stream of water is employed so that the cuttings are lifted to the top, otherwise they would wedge about the drill and finally stop it. This stream serves also to keep the bit cool.

Dry cores in clay and the softer shales can be made with a saw tooth bit. They are desirable because they give a more exact knowledge of the resistance of the material. Unless dry cores are taken, a hard clay or a shale suitable for a foundation might be overlooked. Power is required to rotate the core-drill. The most usual difficulty encountered with core-drilling operations is the sticking of the bit in the hole. This is apt to happen in soft and caving rock, and it is sometimes necessary

and worth while to ream down with a larger bit and case the hole in order to recover the first bit, as diamond bits cost from $600 to $1,000 each. Another serious accident to the diamond bit is the dropping of the rods when pulling them out of a hole. Also a cave, fault, or mud-seam in the rock is always more or less serious; and it often involves reaming down to this point and driving a new casing through. This costs more than the original hole. Loss of water through seams or fissures often requires reaming and casing. The shot drill is subject to the same difficulties as the diamond drill, besides having several additional troubles of its own. It is not as expensive as the diamond drill; and the loss of a bit is not such a serious matter. As the shot are loose under the bit, they roll out when a seam or crack is encountered, leaving the bit without any cutting power. If the seam or crack should bear any considerable amount of water, the shot will be carried away as fast as they are put in, thereby causing a complete blocking of the machine, unless the hole be cased through the seam and continued with a smaller-sized bit, or unless the hole be reamed down to the seam to allow of a larger casing being driven. Another difficulty is that of gauging the stream of water so that it will not carry away the shot, but will be sufficient to wash the cuttings into the calyx. After the calyx is filled and ready for withdrawal it becomes necessary to wash out the hole with a strong jet of water, or to use a sand pump in order to prevent the bit from jamming. No core-lifting attachment is provided, as that would interfere with the feeding of the shot. In order to lift the core, it is necessary to wash in sand so that it becomes jammed in the core-barrel. This is tedious and uncertain; and cores are liable to drop out when pulling up the drill, in which case the core becomes badly broken or even ground to pieces.

The reliability of the records of evidence from these various methods of underground exploration must be taken into consideration when interpreting any borings, as well as the purpose to be served by the said borings. If simply a rock profile is desired the wash-boring method will usually be sufficient, provided that boulders are not prevalent. If the character of the rock, its hardness, thickness, and resistance are desired, the core-drill method should be employed. The tendency of wash borings is to indicate a coarser material than is really encountered, especially with a strong water jet, because the fine material is dissolved and carried off. Clay or silt shows a tendency to appear as sand, and sand to appear as gravel.

The cost of making borings varies so much with different localities that no safe guide can be set without presenting all the data that enter into the said cost. The reader who desires to obtain detailed information concerning this question would do well to consult the standard handbooks on cost data. The core-drilling method is the most expensive, the wash-boring method is less so, and the auger method is the cheapest. However, the result to be accomplished in a great many cases is such

that cheapness of method is by no means the guiding principle; and, moreover, there are many cases in which there is no possible choice of method, owing to existing conditions which render only one applicable.

As a conclusion to this chapter, in the hope that the information offered will prove useful to some of his readers, the author reproduces as follows the blue-printed instructions that his firm furnishes to all of its boring parties:

"Pipe may be purchased close to where the borings are to be made, thus saving freight charges. In cases where the borings are to go to a depth of more than 50 or 60 ft., it is best to get the extra heavy pipe for both two and one-half inch and one inch sizes; but in shallow borings the ordinary thicknesses for two and one-half and one inch pipes will answer.

"For ordinary conditions the pipe is purchased in Kansas City, and about 200 ft. of 2½ in. and 120 ft. of 1 in. pipes should be shipped. This may do the boring for one river crossing, providing it can be pulled after each boring is finished, and so used repeatedly. The casing pipe can nearly always be pulled out when making borings on land, but where there is a great penetration it is a difficult matter to pull pipe from scows. In such cases a small charge of dynamite lowered on the inside so as to break off the pipe at or below the bottom of the river will be the easiest and cheapest way to get rid of it. The pipe above the ground line can be saved, and possibly some more.

"It is advisable and will save a great deal of hard labor to have the pipe, both 2½ in. and 1 in., cut in lengths of about 8 ft.; but two lengths of 16 or 18 ft. of the 2½ in. pipe can be shipped without being cut. All pieces of pipe are to be threaded on both ends. The threads must be deep enough so that the ends of the pipe will come in contact in a coupling. This applies both to the 1 in. and the 2½ in. pipes. A coupling (extra-long hydraulic) should be put on one end of each pipe, and a dozen couplings for 2½ in. pipe and another dozen for 1 in. pipe should be shipped extra.

"Drive caps, Fig. 94 of Fairbanks, Morse & Co.'s Catalogue, can be used only for light driving. As furnished, they are not complete for our method of work; and a hole $1\frac{7}{16}$ in. in diameter must be drilled vertically through the cap. For deep borings the steel drive heads, such as shown in Fig. 48*a*, are required; and they have to be made specially in a machine shop.

"Care should be taken to see that the drills fit the casing pipe, as it may be hard to get them ground down in the field if too large; and if too small they will not work well.

"Use the hydraulic recessed couplings for fastening the drive heads to the casing pipe and to the ram, and be sure the coupling is screwed onto the drive head and onto the pipe as far as possible. This will reduce the danger of stripping the threads while driving.

"Borings should be made as close as possible to the sites of the proposed piers, where such can be known or assumed beforehand. It is well to make the boring just outside the pier, if its location can be determined accurately, so that the casing pipe will not be encountered in sinking the pier, if it should prove impossible to pull it.

"If the borings are to be made in a river of any great width, it is customary to make at least five of them in the water and one on each bank;

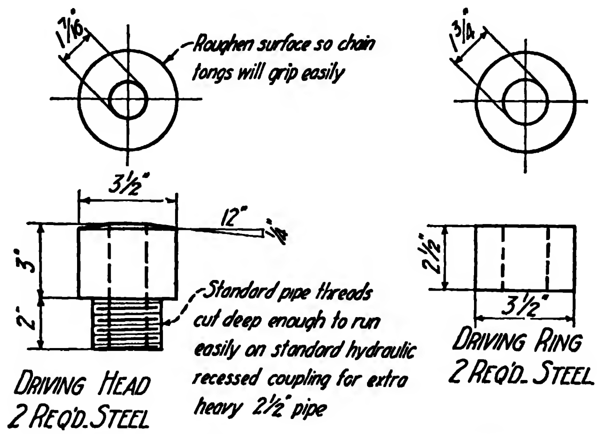


FIG. 48*a*. Steel Drive Head for Driving Casing Pipe.

but if the river is not very wide, three borings may sometimes suffice. In any case the Main Office will instruct as to how many borings will be required.

"The 2½ inch pipe, called the casing pipe, is driven by a ram consisting of a piece of pipe from 8 to 16 feet long, lifted and dropped by from two to four men. The top of the casing pipe is fitted with a drive head, as is also the lower end of the ram. The 1″ pipe, called the wash or drill pipe, usually is not removed during the process of driving down the casing pipe, but remains in place and serves as a guide for the ram. This is clearly shown in Fig. 48*b*.

"When the drill pipe is removed during the driving of the casing, a short length of 1″ piping with a coupling near the centre can be used in place of the drill pipe to act as a guide for the ram. The length of this 1″ pipe above the coupling should not be less than 4½ feet.

"The method of putting on and removing the drive head is shown in Fig. 48*c*. After the drive head has been removed, connection is made from the drill pipe to the pump, as shown in Fig. 48*d*, and the material in the casing pipe is cleaned out according to the directions there given. The casing pipe should not be driven over 6 or 8 feet at a time without cleaning it out. The swivel, shown in Fig. 48*e*, at the connection of the hose to the drill pipe allows the water to pass through it continuously while the drill pipe is being turned around. This is absolutely necessary

when drilling in rock, as it is essential to keep continually turning the pipe in order that the drill may cut a uniformly round hole and thus eliminate the danger of its getting stuck. In soft material the wash

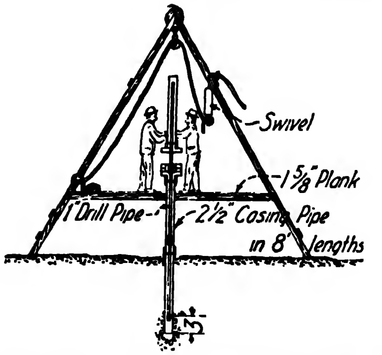


FIG. 48b. Driving Casing for Borings.

NOTE.—The drill point should always be at least 3′ 0″ above the bottom of casing when driving, so that sand and gravel will not be forced up inside of casing and bind the drill.

Coupling of 1″ drill pipe resting on lower drive-head supports drill pipe while driving casing, the two rings forming a protection for coupling as shown.

Drive-heads must be screwed into coupling for full length of thread.

The piece of 1″ pipe above coupling serves as a guide for the ram.

pipe will sink of its own weight as it washes out the earth in the casing pipe, but in hard material it is necessary to raise and drop it, using it as a drill. In such cases the lower end of the wash pipe terminates in

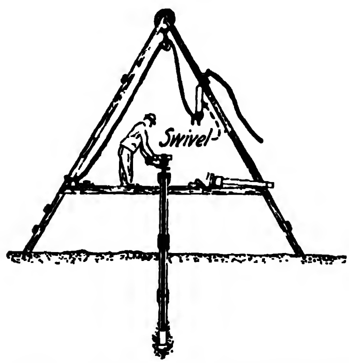


FIG. 48c. Removing or Replacing Drive-head.

NOTE.—To remove or replace drive-head, raise up drill pipe so as to bring the drill well up above the bottom of casing, and hold drill pipe with wrench or line until the coupling is removed and drive-head dropped over top of 1″ pipe. The coupling is then to be screwed on top of 1″ pipe and allowed to drop down on drive-head to support the drill pipe during driving. Reverse operation to remove the drive-head.

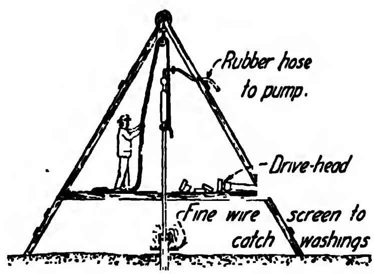


FIG. 48d. Drilling when Making Borings.

NOTE.—To operate drill, raise up and let fall, at the same time keeping a good flow of water passing through pipe.

a cutter, having orifices through which the water passes. For this drilling it is necessary to have a sheave and a line passing to the wash pipe to lift and drop it, as shown in Fig. 48*d*.

"The material washed out of the casing pipe must be caught so that its nature can be determined. A record must be kept of the different

materials penetrated and also of the elevations at which the boring passes from one material into another. A very convenient method of catching this material is to screw a T and a short piece of pipe onto the top of the casing pipe and lead a 1″ hose from the T to the receptacle in which the material is caught.

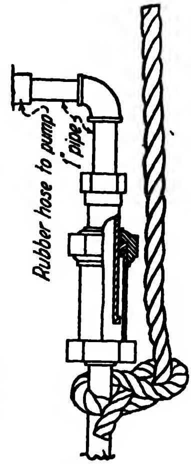


Fig. 48e. Detail of Swivel for Making Borings.

"The casing pipe as well as the drill pipe must be measured, so as to know exactly when the drill is at the bottom of the casing pipe. If the bottom of the casing pipe is in sand or gravel, it is best not to try to go below the casing pipe with the wash pipe, as the sand or gravel will cave in and possibly cause trouble. The pump must be kept working until the wash water coming out of the casing pipe carries no material, as this material is liable to settle around the drill pipe and freeze it in when the pump is stopped. This can also be avoided by raising the drill pipe a few feet above the bottom of the hole before stopping the pump.

"If clay is encountered, the casing can be stopped and the drill pipe alone used; but if sand or gravel is met with below the stratum of clay, then the casing must be driven down through the clay, for neither the sand nor the gravel will stand up, and it will be impossible to drill through without the casing. In going through clay, much greater progress can be made if the drill pipe is turned in the same manner as when drilling in rock.

"If boulders are encountered so close to the surface that the casing pipe can easily be pulled, then the said pipe must be withdrawn, the boats shifted a little to another position, and the casing re-driven. It is much easier to dodge boulders when near the surface than to try to work through them. If boulders are encountered at a great depth, it will be best to go through them. The easiest method is to rig up the apparatus to pull the pipe; but before doing so the case must be washed out to the boulder, and then a stick of dynamite, say ¼ lb., must be weighted and lowered onto the boulder, then the pipe must be pulled 4 or 5 ft. above the latter and the dynamite fired. Waterproof fuse or electric battery must be used to explode the dynamite. If the casing pipe is too deep to be easily withdrawn, then the expansion drill must be used to pierce the boulder. This will be a slow job, but it must be done.

"When bed-rock is encountered, the expansion drill should be used to drill into it at least 2 inches, then the casing pipe must be driven into the hole made. This will cut off the flow of sand and make the remaining drilling much easier. The expansion bit should be removed and the regular drill bit used to drill into bed-rock. If it proves to be hard, from 4 to 5 feet will be a sufficient depth to penetrate; but should it be shale or cemented gravel, then it must be drilled into from 10 to 12 feet.

"It will be necessary to work six men on borings. These can generally be picked up in the vicinity of the work.

"The scaffolding shown in Figs. 48*b*, 48*c*, and 48*d* has only one working platform. It is much more convenient and much easier on the men to have at least two working platforms, and the work can be done much more quickly. The sketch illustrating the barges in position with scaffold erected (Fig. 48*f*) shows a better arrangement, as it gives plenty of working room both for handling the pipes and for driving the casing.

"For work in the river it is preferable to have two small scows to

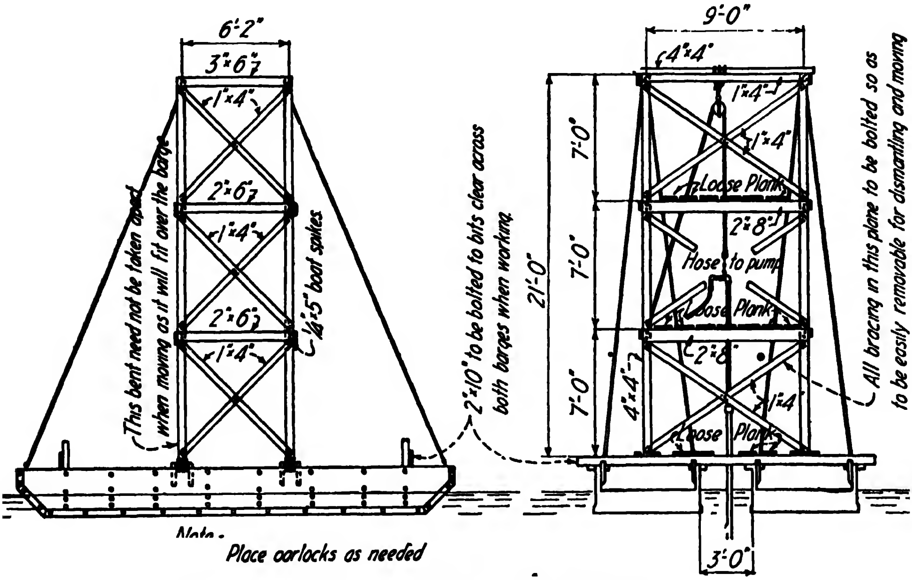


FIG. 48*f*. Equipment for Making Borings from Barges.

work on, providing they can be rented. If they are not obtainable, one medium-sized scow will suffice. In case the two small scows are available, they can be fastened together, and a tower with suitable working platforms erected thereon, as shown by Fig. 48*f*.

"In case the two scows are not available, the work can be done from one scow. This can be accomplished with a tower of the same dimensions resting on two timbers extending over one end. They must be bolted or secured rigidly to the scow so that there shall be no danger of their tipping up. A little less than one-half of the tower can be on the scow.

"In case no scows are available, it will be necessary to build a couple of small ones. Fig. 48*g* shows a very satisfactory design. To hold the scows it will be necessary to anchor them from each corner. Boxes filled with stone will suffice for anchorage, but the regular iron anchor will be much better, especially on a stream with swift current. The anchor lines to each anchor must be at least 150 ft. long in order to get good

results; but it will not be necessary to provide either anchors or lines until the situation is looked over. As a general thing, any one who has scows to rent has anchors and lines also.

"When boring on navigable water, it may be necessary to employ a watchman at night. This will largely depend on the number of boats

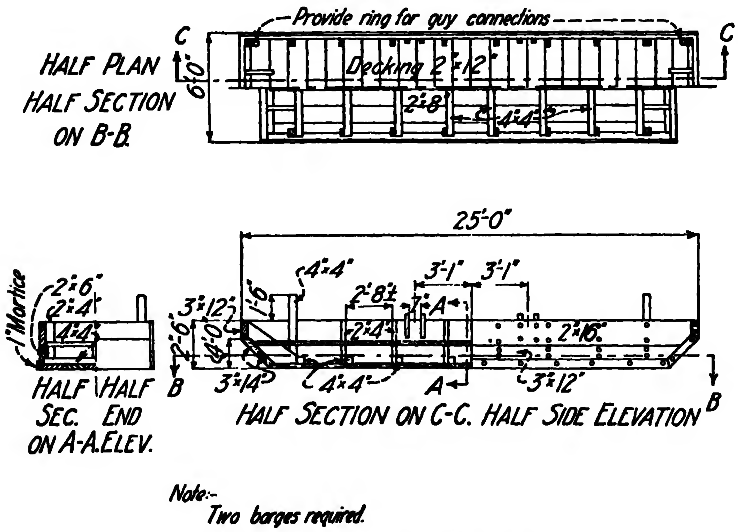


FIG. 48g. Details of Barge for Making Boring.

plying the stream, but in any event a red light must be placed in the tower during the night. It must be so located as to be seen from all sides.

"A skiff will be needed to cross to and from the barges. It will be advisable to employ a man who owns a skiff, paying him about 50 cents per day for his skiff, and for his work the same wages as the other men in the crew receive, which is generally $2.00 per day. In case a man and skiff cannot be obtained, a skiff can be bought, rented, or built.

"In making borings on sand bars at some distance away from water, it will be necessary to drive a well point through the sand until water is reached, in order to supply it for pumping. If it happens to be so deep to water that the pump will not raise it, a couple of barrels must be secured and a man employed to carry water thereto from the river. When using water from barrels it can be employed continuously by collecting it as it leaves the casing pipe. This may be done by procuring a T connection, screwing it on top of the casing pipe, placing a short piece of 2½" pipe on top of the T, and inserting another short piece into it horizontally. To this a section of hose can be attached and the end placed in the barrel so as to catch the water as it flows from the casing pipe.

"When the job is finished do not ship any pipe with the tools, unless you are going to another job where the pipe on hand could be shipped and

used more cheaply than to buy new pipe. Sell the pipe if possible; if unable to do so, discard it.

"Under special conditions it may be more economical to use a gasoline engine to run the pump and to lift the drill pipe when drilling instead of employing man power. A two-horse-power engine will furnish ample power to do this. The engine, No. 140, shown in Fairbanks-Morse & Company Catalogue No. 60, page 255, is suitable for this purpose. The walking beam shown is not required, but the pump can be connected directly to the pitman rod there indicated. The minimum stroke with this engine (5″) at the given speed (47 r.p.m. of pump gear) will give too much water, so that it will be necessary to shorten the stroke by connecting the pitman rod to the upright piece of the pump handle a sufficient distance above the piston of the pump to give the required length of stroke. Probably a 2″ stroke will be sufficient. For lifting the drill pipe it will be necessary to rig up a spool on a shaft independent of the engine, with a pulley for a belt connection to the pulley on the engine. By taking a couple of turns around this spool with the line from the drill pipe, the latter is easily raised by a slight pull on the line leading from the spool and dropped by slacking on the same. The above outfit requires three men to operate. It can be used economically where labor is scarce and wages are high. Another advantage under such conditions is that the work is much easier and, therefore, there is not the danger of continually losing the men about the time they get accustomed to the work. Where the material in which the boring is being made is such that the drill pipe can be carried down without the casing pipe the advantage of the engine is much increased, and, conversely, where the casing pipe has to be driven down all the way the use of the engine loses much of its advantage. This is because with hand operation the entire six men can be utilized when driving, while three men will not make very good progress where there is much driving to do. It is possible to raise the ram with the engine, but driving with the engine raising the ram is not nearly so effective. Fig. 48*h* shows the arrangement of the gasoline engine, pump, etc.

"Before the work is started, employers' liability insurance is to be taken out on all men employed upon or connected with the work. This can usually be obtained in the town nearest to the site of the borings by application to some insurance agent. We want to be thoroughly protected in the work; and, therefore, proper insurance must be taken out.

"Usually we are given by the company stakes on the bridge tangent; and then borings will be located by their station number. Where we establish the bridge tangent the station numbering is ordinarily fixed by some natural object, say the centre line of some cross street, a railroad track, etc. For ordinary cases, or where the water is not more than 500 feet across, the position of each boring can be determined by measuring out with a tape, or with a wire and then measuring the wire. For wider

streams it will be necessary to lay out a rough triangulation system and measure the angle between base line and boring. Extreme accuracy is not essential, as a variation of a couple of feet is no serious matter. The angle can be read when convenient and the plus of the boring figured.

"Usually we are given a bench mark, or else some permanent bench mark referred to some assumed base is selected. It is well to place a gauge so that

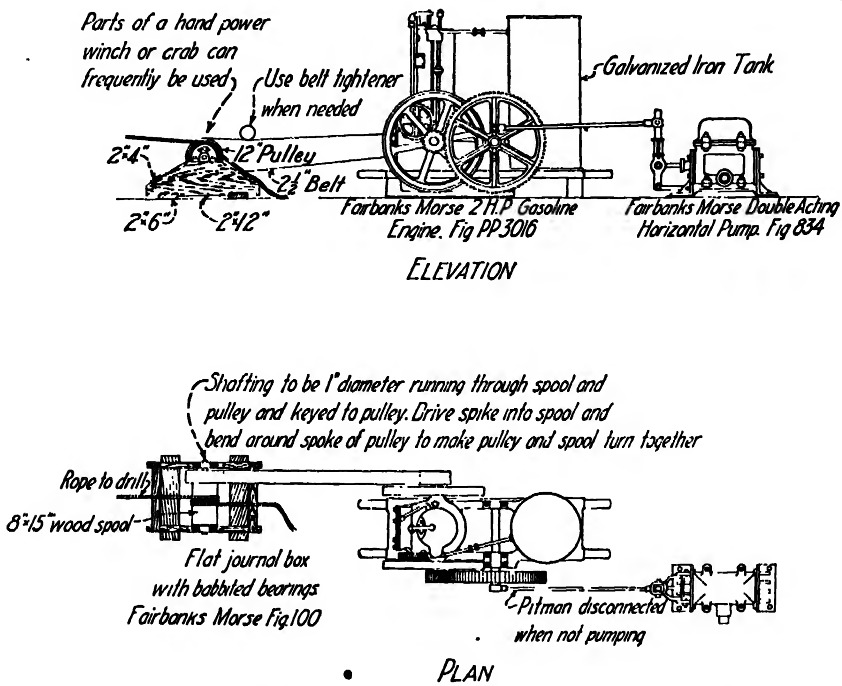


FIG. 48*h*. Arrangement of Gasoline Engine for Making Borings.

the elevation of the water can be noted at least once a day. Elevations of pipe are generally determined from the water and so referred to datum. It is well to establish levels at once and refer all measurements to proper datum.

"As soon as the engineer reaches the site he should write a letter to the Main Office, giving full particulars as to how the conditions appear to him. Every day thereafter a daily report is to be sent on the blanks supplied. (See Fig. 48*i*.) One report is to be mailed each night giving the information for that day. Special notes may be made on the reports so that no other letters are necessary.

"When the work is concluded, a final letter should be written, advising as to the disposal of tools, equipment, old pipe, etc., and sending bills of lading for shipments.

"Take receipts for all expenditures for materials and wages, rents, etc., on the blanks furnished."

Unfortunately, these regulations are not very well formulated; but this is not the fault of the War Department, as it once tried to have a bill passed by Congress to establish general rules for bridging the Mississippi River and most of its tributaries, but it did not become a law.

On March 23, 1906, Congress approved a bill "to regulate the construction of bridges over navigable waters." It reads as follows:

"An Act to regulate the construction of bridges over navigable waters.

"*Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled*, That when, hereafter, authority is granted by Congress to any persons to construct and maintain a bridge across or over any of the navigable waters of the United States, such bridge shall not be built or commenced until the plans and specifications for its construction, together with such drawings of the proposed construction and such map of the proposed location as may be required for a full understanding of the subject, have been submitted to the Secretary of War and Chief of Engineers for their approval, nor until they shall have approved such plans and specifications and the location of such bridge and accessory works; and when the plans for any bridge to be constructed under the provisions of this Act have been approved by the Chief of Engineers and by the Secretary of War it shall not be lawful to deviate from such plans, either before or after completion of the structure, unless the modification of such plans has previously been submitted to and received the approval of the Chief of Engineers and of the Secretary of War.

"SEC. 2. That any bridge built in accordance with the provisions of this Act shall be a lawful structure and shall be recognized and known as a post route, upon which no higher charge shall be made for the transmission over the same of the mails, the troops, and the munitions of war of the United States than the rate per mile paid for the transportation over any railroad, street railway, or public highway leading to said bridge; and the United States shall have the right to construct, maintain, and repair, without any charge therefor, telegraph and telephone lines across and upon said bridge and its approaches; and equal privileges in the case of said bridge and its approaches shall be granted to all telegraph and telephone companies.

"SEC. 3. That all railroad companies desiring the use of any railroad bridge built in accordance with the provisions of this Act shall be entitled to equal rights and privileges relative to the passage of railway trains or cars over the same and over the approaches thereto upon payment of a reasonable compensation for such use; and in case of any disagreement between the parties in regard to the terms of such use or the sums to be paid all matters at issue shall be determined by the Secretary of War upon hearing the allegations and proofs submitted to him.

"SEC. 4. That no bridge erected or maintained under the provisions of this Act shall at any time unreasonably obstruct the free navigation of the waters over which it is constructed, and if any bridge erected in accordance with the provisions of this Act shall, in the opinion of the Secretary of War, at any time unreasonably obstruct such navigation, either on account of insufficient height, width of span, or otherwise, or if there be difficulty in passing the draw opening or the drawspan of such bridge by rafts, steamboats, or other water craft, it shall be the duty of the Secretary of War, after giving the parties interested reasonable opportunity to be heard, to notify the persons owning or controlling such bridge so to alter the same as to render navigation through or under it reasonably free, easy, and unobstructed, stating in such notice the changes required to be made, and prescribing in each case a reasonable time in which to make such changes, and if at the end of the time so specified the changes so required have not been made, the persons owning or controlling such bridge shall be deemed guilty of a violation of this Act; and all such alterations shall be made and all such obstructions shall be removed at the expense of the persons owning or operating said bridge. The

persons owning or operating any such bridge shall maintain, at their own expense, such lights and other signals thereon as the Secretary of Commerce and Labor shall prescribe. If the bridge shall be constructed with a draw, then the draw shall be opened promptly by the persons owning or operating such bridge upon reasonable signal for the passage of boats and other water craft. If tolls shall be charged for the transit over any bridge constructed under the provisions of this Act, of engines, cars, street cars, wagons, carriages, vehicles, animals, foot passengers, or other passengers, such tolls shall be reasonable and just, and the Secretary of War may, at any time, and from time to time, prescribe the reasonable rates of toll for such transit over such bridge, and the rates so prescribed shall be the legal rates and shall be the rates demanded and received for such transit.

"SEC. 5. That any persons who shall fail or refuse to comply with the lawful order of the Secretary of War or the Chief of Engineers, made in accordance with the provisions of this Act, shall be deemed guilty of a violation of this Act, and any persons who shall be guilty of a violation of this Act shall be deemed guilty of a misdemeanor and on conviction thereof shall be punished in any court of competent jurisdiction by a fine not exceeding five thousand dollars, and every month such persons shall remain in default shall be deemed a new offense and subject such persons to additional penalties therefor; and in addition to the penalties above described the Secretary of War and the Chief of Engineers may, upon refusal of the persons owning or controlling any such bridge and accessory works to comply with any lawful order issued by the Secretary of War or Chief of Engineers in regard thereto, cause the removal of such bridge and accessory works at the expense of the persons owning or controlling such bridge, and suit for such expense may be brought in the name of the United States against such persons, and recovery had for such expense in any court of competent jurisdiction; and the removal of any structures erected or maintained in violation of the provisions of this Act or the order or direction of the Secretary of War or Chief of Engineers made in pursuance thereof may be enforced by injunction, mandamus, or other summary process, upon application to the circuit court in the district in which such structure may, in whole or in part, exist, and proper proceedings to this end may be instituted under the direction of the Attorney-General of the United States at the request of the Secretary of War; and in case of any litigation arising from any obstruction or alleged obstruction to navigation created by the construction of any bridge under this Act, the cause or question arising may be tried before the circuit court of the United States in any district which any portion of such obstruction or bridge touches.

"SEC. 6. That whenever Congress shall hereafter by law authorize the construction of any bridge over or across any of the navigable waters of the United States, and no time for the commencement and completion of such bridge is named in said Act, the authority thereby granted shall cease and be null and void unless the actual construction of the bridge authorized in such Act be commenced within one year and completed within three years from the date of the passage of such Act.

"SEC. 7. That the word 'persons' as used in this Act shall be construed to import both the singular and the plural, as the case demands, and shall include municipalities, quasi-municipal corporations, corporations, companies, and associations.

"SEC. 8. That the right to alter, amend, or repeal this Act is hereby expressly reserved as to any and all bridges which may be built in accordance with the provisions of this Act, and the United States shall incur no liability for the alteration, amendment, or repeal thereof to the owner or owners or any other persons interested in any bridge which shall have been constructed in accordance with its provisions."

The preceding "Act" is very general in its nature, and is both interesting and useful to bridge engineers as far as it goes; but much more detailed information is necessary in order to prepare properly the plans

when some powerful corporation for selfish reasons is opposing the construction of the bridge, the applicant will have a fight on his hands that will keep him continually employed for some time.

When any formal opposition to a bridge project is brought to the attention of the War Department, if the Secretary of War deem it necessary, he names a date and place for a public hearing; and ample notice is then given by advertisements in those of the leading daily papers which are most likely to reach all the parties interested in the controversy. At this hearing the district engineer officer usually presides, but in some important cases three of the U. S. Army engineers act as judges, and the proceedings are quite similar to those of a court of law. After the evidence is all in and duly considered, the Board renders its decision; which is almost always final, as it would be exceedingly difficult to reverse. Such hearings are usually characterized by the eminent fairness of all the proceedings. Every one interested is given a courteous hearing, and the judges almost invariably render an impartial verdict, basing their decision upon the principle of the "greatest good for the greatest number." Even the defeated parties generally recognize the justice of the award; and very seldom is there any complaint heard about partiality or unfairness. As the members of the U. S. Engineer Corps are the guardians of the country's navigation interests, one might think that they are liable to be prejudiced on the side of river traffic and opposed to the railroads; but when river men endeavor to block a legitimate project by unwarranted allegations of injury to navigation, they are soon made to understand that they will not be allowed to stop the material progress of the country because some proposed construction may not favor their personal aims.

The army engineers endeavor to make it as easy as possible for an applicant to get his plans approved; and when they are convinced of the necessity for haste, they will make their decision with very little delay. While they are particular about the correctness of the hydrographical map, they require but little data concerning the plans for the structure —simply a profile of the crossing showing the outlines of the piers, the skeleton of the trusses, and the corresponding plan giving main dimensions and location of piers and abutments. They are not concerned with the strength of the superstructure nor with the specifications upon which the bridge is to be built; for they consider that the owner is sufficiently interested not to permit of any construction that is going to fail. Moreover, if it should, the débris would soon be removed by the Government at the owner's expense. In examining the plans, they make it their business to see that the location not only complies with the law in respect to both the spacing and the position of piers and abutments, but also that the bridge, when completed, will not dam the water too much nor cause currents which would be prejudicial to navigation. Each proposed location is considered upon its own merits, and it will not be ap-

proved, although complying with both the law and the custom of the Department, in case that any peculiar features necessitate other restrictions. The questions involved are treated from the broad standpoint of common sense, and the only red tape that the applicant is liable to encounter is the little piece used to tie up his approved plans with the official papers by which they are accompanied.

While it is not practicable for any one to determine in advance what layout of spans for any proposed crossing will meet with the approval of the War Department, it is generally known what the usual requirements are for each principal river. By the way, though, these very properly vary on the different stretches of the stream, being more severe near the mouth than in the vicinity of the head of navigation. On the Missouri River, as high up at least as Omaha, the minimum clear openings between piers are four hundred (400) feet for high bridges, and two hundred (200) feet for the swing spans, and three hundred (300) feet for the fixed spans of low bridges; and the clear headway above high water is from fifty-five (55) to fifty (50) feet for high bridges and ten (10) feet for low bridges. However, concessions are sometimes made in respect to the vertical clearance of low bridges; because all that really needs to be assured is that the bottom chords are high enough to avoid danger from injury by floating trees and logs.

As the width of river is rarely such that a certain number of spans of minimum length will exactly cover the stream, it is evident that in most cases there will arise the question of whether it is best to shorten or lengthen each span or to place a short span at one end of the bridge. The decision will generally be in favor of either the last-mentioned method or the equal lengthening of all the spans, as the Department is loth to break its established rules, and will not do so if it can be avoided.

When an engineer is retained upon a bridge project for the crossing of a navigable stream, of which he does not know the War Department's requirements for clear span and clear headway, the first step for him to take is to write the Chief of Engineers and request him to state, either officially or otherwise, as he may prefer, what in ordinary cases would be the said requirements. At the same time he should endeavor to learn what is the Department's interpretation of the term "High Water," because on some rivers the Government has established standard high water grade lines that are materially lower than the extreme high water elevations; and if such a standard can be used for the high water mentioned in the Company's charter, a material saving in both grades and money can often be effected. This is especially true in the case of projected low bridges to be built as close to the water as practicable.

The following quotations are extracted from a Government publication entitled "Laws for the Protection and Preservation of the Navigable Waters of the United States." Only those clauses which touch either directly or indirectly on bridgework have been chosen. As they

are taken from Acts passed at several different times, they involve a certain amount of repetition, which it is hoped the reader will pardon:

"That it shall not be lawful to construct or commence the construction of any bridge, dam, dike, or causeway over or in any port, roadstead, haven, harbor, canal, navigable river, or other navigable water of the United States until the consent of Congress to the building of such structures shall have been obtained and until the plans for the same shall have been submitted to and approved by the Chief of Engineers and by the Secretary of War: PROVIDED, That such structures may be built under authority of the legislature of a State across rivers and other waterways the navigable portions of which lie wholly within the limits of a single State, provided the location and plans thereof are submitted to and approved by the Chief of Engineers and by the Secretary of War before construction is commenced: AND PROVIDED FURTHER, That when plans for any bridge or other structure have been approved by the Chief of Engineers and by the Secretary of War, it shall not be lawful to deviate from such plans either before or after completion of the structure unless the modification of said plans has previously been submitted to and received the approval of the Chief of Engineers and of the Secretary of War.

"That the creation of any obstruction, not affirmatively authorized by Congress, to the navigable capacity of any of the waters of the United States is hereby prohibited; and it shall not be lawful to build or commence the building of any wharf, pier, dolphin, boom, weir, breakwater, bulkhead, jetty, or other structure in any port, roadstead, haven, harbor, canal, navigable river, or other water of the United States, outside established harbor lines, or where no harbor lines have been established, except on plans recommended by the Chief of Engineers and authorized by the Secretary of War; and it shall not be lawful to excavate or fill, or in any manner to alter or modify the course, location, condition, or capacity of, any port, roadstead, haven, harbor, canal, lake, harbor of refuge, or inclosure within the limits of any breakwater, or of the channel of any navigable water of the United States, unless the work has been recommended by the Chief of Engineers and authorized by the Secretary of War prior to beginning the same.

"That where it is made manifest to the Secretary of War that the establishment of harbor lines is essential to the preservation and protection of harbors he may, and is hereby, authorized to cause such lines to be established, beyond which no piers, wharves, bulkheads, or other works shall be extended or deposits made, except under such regulations as may be prescribed from time to time by him: PROVIDED, That whenever the Secretary of War grants to any person or persons permission to extend piers, wharves, bulkheads, or other works, or to make deposits in any tidal harbor or river of the United States beyond any harbor lines established under authority of the United States, he shall cause to be ascertained the amount of tide-water displaced by any such structure or by any such deposits, and he shall, if he deem it necessary, require the parties to whom the permission is given to make compensation for such displacement either by excavating in some part of the harbor, including tide-water channels between high and low water mark, to such an extent as to create a basin for as much tide water as may be displaced by such structure or by such deposits, or in any other mode that may be satisfactory to him.

"That every person and every corporation that shall violate any of the provisions of sections nine, ten, and eleven of this Act, or any rule or regulation made by the Secretary of War in pursuance of the provisions of the said section eleven, shall be deemed guilty of a misdemeanor, and on conviction thereof shall be punished by a fine not exceeding twenty-five hundred dollars nor less than five hundred dollars, or by imprisonment (in the case of a natural person), not exceeding one year, or by both such punishments, in the discretion of the court. And further, the removal of any structures or parts of structures erected in violation of the provisions of the said sections may be enforced by the injunction of any circuit court exercising jurisdiction in any district in

which such structures may exist, and proper proceedings to this end may be instituted under the direction of the Attorney-General of the United States.

"That it shall not be lawful to throw, discharge, or deposit, or cause, suffer, or procure to be thrown, discharged, or deposited either from or out of any ship, barge, or other floating craft of any kind, or from the shore, wharf, manufacturing establishment, or mill of any kind, any refuse matter of any kind or description whatever other than that flowing from streets and sewers and passing therefrom in a liquid state, into any navigable water of the United States, or into any tributary of any navigable water from which the same shall float or be washed into such navigable water; and it shall not be lawful to deposit, or cause, suffer, or procure to be deposited material of any kind in any place on the bank of any navigable water, or on the bank of any tributary of any navigable water, where the same shall be liable to be washed into such navigable water, either by ordinary or high tides, or by storms or floods, or otherwise, whereby navigation shall or may be impeded or obstructed: PROVIDED, That nothing herein contained shall extend to, apply to, or prohibit the operations in connection with the improvement of navigable waters or construction of public works, considered necessary and proper by the United States officers supervising such improvement of public work: AND PROVIDED FURTHER, That the Secretary of War, whenever in the judgment of the Chief of Engineers anchorage and navigation will not be injured thereby, may permit the deposit of any material above mentioned in navigable waters, within limits to be defined and under conditions to be prescribed by him, provided application is made to him prior to depositing such material; and whenever any permit is so granted the conditions thereof shall be strictly complied with, and any violation thereof shall be unlawful.

"That whenever the Secretary of War shall have good reason to believe that any railroad or other bridge now constructed, or which may hereafter be constructed, over any of the navigable waterways of the United States is an unreasonable obstruction to the free navigation of such waters on account of insufficient height, width of span, or otherwise, or where there is difficulty in passing the draw opening or the draw span of such bridge by rafts, steamboats, or other water craft, it shall be the duty of the said Secretary, first giving the parties reasonable opportunity to be heard, to give notice to the persons or corporations owning or controlling such bridge so to alter the same as to render navigation through or under it reasonably free, easy, and unobstructed; and in giving such notice he shall specify the changes recommended by the Chief of Engineers that are required to be made, and shall prescribe in each case a reasonable time in which to make them. If at the end of such time the alteration has not been made, the Secretary of War shall forthwith notify the United States district attorney for the district in which such bridge is situated, to the end that the criminal proceedings hereinafter mentioned may be taken. If the persons, corporation, or association owning or controlling any railroad or other bridge shall, after receiving notice to that effect, as hereinbefore required, from the Secretary of War, and within the time prescribed by him willfully fail or refuse to remove the same or to comply with the lawful order of the Secretary of War in the premises, such persons, corporation, or association shall be deemed guilty of a misdemeanor, and on conviction thereof shall be punished by a fine not exceeding five thousand dollars, and every month such persons, corporation, or association shall remain in default in respect to the removal or alteration of such bridge shall be deemed a new offense, and subject the persons, corporation, or association so offending to the penalties above prescribed: PROVIDED, That in any case arising under the provisions of the section an appeal or writ of error may be taken from the district courts or from the existing circuit courts direct to the Supreme Court either by the United States or by the defendants.

"That it shall be the duty of all persons owning, operating, and tending the drawbridges now built, or which may hereafter be built across the navigable rivers and other waters of the United States, to open, or cause to be opened, the draws of such bridges under such rules and regulations as, in the opinion of the Secretary of War, the public

interests require to govern the opening of draw bridges for the passage of vessels and other water craft, and such rules and regulations, when so made and published, shall have the force of law. Every such person who shall willfully fail or refuse to open, or cause to be opened, the draw of any such bridge for the passage of a boat or boats, or who shall unreasonably delay the opening of said draw after reasonable signal shall have been given, as provided in such regulations, shall be deemed guilty of a misdemeanor, and on conviction thereof shall be punished by a fine of not more than two thousand dollars nor less than one thousand dollars, or by imprisonment (in the case of a natural person) for not exceeding one year, or by both such fine and imprisonment, in the discretion of the court: PROVIDED, That the proper action to enforce the provisions of this section may be commenced before any commissioner, judge, or court of the United States, and such commissioner, judge, or court shall proceed in respect thereto as authorized by law in case of crimes against the United States. PROVIDED FURTHER, That whenever, in the opinion of the Secretary of War, the public interests require it, he may make rules and regulations to govern the opening of drawbridges for the passage of vessels and other water craft, and such rules and regulations, when so made and published, shall have the force of law, and any violation thereof shall be punished as hereinbefore provided.

"That expenses incurred by the Engineer Department in all investigations, inspections, hearings, reports, service of notice, or other action incidental to examination of plans or sites of bridges or other structures built or proposed to be built in or over navigable waters, or to examinations into alleged violations of laws for the protection and preservation of navigable waters, or to the establishment or marking of harbor lines, shall be payable from any funds which may be available for the improvement, maintenance, operation, or care of the waterways or harbors affected, or if such funds are not available in sums judged by the Chief of Engineers to be adequate, then from any funds available for examinations, surveys, and contingencies of rivers and harbors."

The following extract from a Government document, issued by the Department of Commerce and Labor and entitled "Laws Relative to the Light-House Establishment," bears upon the subject of bridges:

"That any person, firm, company, or corporation required by law to maintain a light or lights upon any bridge or abutments over or in any navigable waters, who shall fail or refuse to maintain such light or lights, or to obey any of the lawful rules and regulations relating to the same, shall be deemed guilty of a misdemeanor and be subject to a fine not exceeding the sum of one hundred dollars for each offense, and each day during which such violation shall continue shall be considered as a new offense."

It is not worth while to reproduce here all the Government rules and regulations for the lighting of bridges over navigable streams; but the officers of any company owning or operating such structures should correspond with the War Department so as to ascertain just what the requirements are in respect to each particular case, then adhere strictly to such requirements.

CHAPTER LI

HYDROGRAPHIC SURVEYS FOR THE BRIDGING OF NAVIGABLE WATERS

FROM the preceding chapter, it is seen that the War Department requires certain data submitted along with the application for a permit to bridge any navigable stream. To secure such data it is necessary to make a survey. While it is being made it is well to enlarge its scope so as to secure all the information required in determining the layout and the possible treatment of the river so as better to protect the structure.

The best site having been settled upon for the location of the bridge, it remains to supplement the preliminary survey with the information needed by the War Department in passing on the application. The first step is to run an accurate traverse line on each side of the river and as near the bank as possible, so that "cross shots" may be taken as a check on the accuracy of the work. These traverse lines should extend at least one mile above the bridge and a half mile below it, or further if it be necessary to locate bends that will affect the matter of shore protection. These two traverse lines should be accurately chained and their angles (preferably azimuths) carefully read, so that with the "cross shots" a control system will be established as a basis for the further work of getting topography and hydrography. The level should be run over the traverse lines, and an elevation should be established at each angle point for future use, these angle points thus becoming bench marks.

This system of control having been completed, it becomes an easy matter to start from any of the angle points and, by stadia, to secure the topography of the valley affected by floods, and to locate any improvements in the area under consideration. Also from these same angle points the positions of the different soundings can be readily located by stadia. This method requires only one transit and one transitman. It gives positive results which cannot be obtained by the method of trying to get the boat on range between two flag-poles. It has a further advantage over the double transit method in that the stadia method is definite for all points, whereas the double transit method becomes uncertain as the two lines of sight approach parallelism.

For the purpose of making soundings, a light pole graduated in feet and tenths is best for shallow streams and moderate velocities. For deeper rivers or stronger currents a lead line is employed; and a fine steel wire and heavy lead may be used for very swift current. The man making the soundings gives the signal to the transitman on shore as to when to observe position; and at the same time he notes the depth and

calls it to the assistant in the boat, who records the exact time and the depth. Care must be taken to ensure that the pole or lead line is vertical and that the lead is on the bottom. It is absolutely essential that all the watches of the party used in recording time agree precisely; for if not, serious trouble may be encountered in the plotting. The transitman on shore reads the azimuth and the stadia and notes the exact time, recording all three of these in his book, either personally or by calling them to an assistant. The vernier is left unclamped for rapid motion of the transit, which is preferably controlled with the left hand following the motion of the boat. The telescope should be clamped on the horizontal axis and manipulated by the gradienter screw with the right hand, the watch lying open on the plate of the instrument. With a little practice the motion of the boat can readily be followed and readings rapidly made. The transitman signals the boat when he is through making an observation. Where the shots are not too close together he can do his own recording; but, otherwise, he will require an assistant to keep the notes. On clear days half mile shots can be taken. The stadia board can be slipped into a socket in the boat, prepared for that purpose; and it can be steadied by one of the crew.

The plotting of these notes is a simple matter and can readily be done with a large paper protractor and paper scale. The soundings should be reduced to elevations so that contours can be drawn for the river bed as well as for the flood plain. All data pertaining to high and low water lines should be placed on the map.

It will be necessary to ascertain the direction and strength of the current. If a current meter is not available, floats can be used for the purpose. A piece of 4″ × 4″ timber about three feet long makes a good float. It can be loaded at one end with pieces of iron so that it will remain vertical in the water, weight enough being used to submerge the stick to within a few inches of the water's surface. By having a hole at the end, a small flag can be employed, thus insuring that the float will be readily seen by the observer on shore. The float can be dropped from the boat, the position of which is determined by the transitman in the manner previously described; and it can be picked up by another boat lower down stream, the signal being given at the same instant to note the position and the exact time. If two boats are not available, range poles can be used for the lower station, and a man located on shore in line with the poles so as to signal the transitman when the float crosses the line. It would be best to repeat this observation several times in order to obtain a reliable average. The boat can follow the float down and pick it up after it crosses the line. In case of a wide stream it would be best to measure the velocity along different longitudinal sections of the channel. It should be remembered that the velocity thus ascertained is surface velocity, and is less than the maximum and greater than the mean.

These various data should be incorporated into a neat hydrographic map and profile for presentation with the application. The map should show the banks of the stream, the location of the proposed bridge, the high and low water lines, the observed water lines, the different directions and velocities of the current, and the soundings giving the depths at the various points as actually recorded. The survey should be properly tied in to a section corner so that its location can be identified on any of the standard maps.

CHAPTER LII

ÆSTHETICS IN DESIGN

WITH the recession of pioneering conditions, the accumulation of wealth, and the general acquisition of culture there comes a stronger and more insistent call for structures that please the eye; hence the engineering profession, in order to keep pace with the advancing demands upon it, will need to give more and more attention to the æsthetic qualities of its creations. To do this the engineer must have some conception of those underlying principles of the science of æsthetics which affect his work, and also a realization of whose eye he should strive to please.

The foundation of æsthetics is of the subjective order—the quality of the impression made on the mind of the observer by the thing observed. By varying either one of these basic factors (*i. e.*, the mentality receiving the impression or the external object causing it) the impression will be changed. Witness the different conceptions of the beautiful and artistic held by the various divisions of the human species during the successive stages of their evolution. The condition of mental development has much to do with the pleasing effect, or lack of it, produced by the object. Hence the science of æsthetics is of a relative order and will gradually change with the developing mind. We cannot as yet regard its precepts as absolute and immutable. Such a condition can be established only when the underlying basic principle of artistic science is correlated with psychology and expressed in terms thereof. That basic law will then account for and predict the changing standards and precepts of æsthetics. This point of view is valuable in approaching the subject of artistic design and in selecting a standard of excellence by which to measure the deficiencies of engineering structures from the æsthetic point of view. Artists and architects have formulated various tenets during the past centuries defining their conceptions of the artistic. To these the engineer must look for his first provisional standard for comparison, remembering their origin and the conditions attending it, as well as the general limitations surrounding any such standard.

The best presentation that the author has ever seen of the philosophy underlying artistic design as related to bridges is that of his friend, the late Henry Van Brunt, Esq., who at the time of its writing was acknowledged by his professional brethren to be one of the foremost living masters of the science of architecture. Upon request Mr. Van Brunt set forth his ideas in a letter to the author, written specially for publication in his *De Pontibus;* and as the truths stated therein are as pertinent

today as they were at the time they were written, the said letter is herewith reproduced.

"My Dear Mr. Waddell:

"After looking over a portion of your instructive treatise on bridges, I find it quite impossible to comply with your request to furnish you with practical suggestions from an architectural point of view as to grace and beauty of design in such structures. As these qualities must be developed from the structure itself, as they must be evolved from its inherent economical and practical conditions, and as they cannot be successfully applied to it as an afterthought, it would be unbecoming for any layman to attempt to show by what process this evolution is to be accomplished. The problem is not an easy one; it is not to be solved by theory, or by any accident of invention or ingenuity. At present, at least, it can only be treated on general lines. Indeed, there is no one living, I fear, who can suggest a specific and easily applied remedy for that disease of engineering which is expressed in the curious fact that the most perfect results of science, at least in the art of steel-bridge building as now understood and inculcated, do not recognize any theory of beauty in line or mass.

"It is the business of the architect to express structure and purpose with beauty. It is the business of the engineer, as I understand it, to make structures strong, durable, rigid, and economical; to apply pure science, excluding, as a matter of principle, any device of art which, for the sake of mere ornamentation, may add to his fabric a pound of unnecessary weight or a dollar of unnecessary cost.

"It cannot be denied that to whatever extent the exercise of this principle may have affected the practice of engineers, they have succeeded, especially as regards bridge-building, in developing a structure which is in every essential respect orderly, consistent, and progressive from a practical point of view. From year to year this development toward mechanical perfection has been plainly visible. The structure of ten years ago has been reasonably and properly superseded by another and better structure, indicating a process of growth without a shadow of caprice; in this process discovery and invention have had their proper influence, uninterrupted by any conservative prejudice or by any theory of design which does not rest directly on practical considerations. But, as I have already observed, this admirable and prolific progress has not carried with it a corresponding progress in grace and beauty of design. In fact, these qualities seem to appear in an inverse proportion to the development of the structural scheme toward the practical idea of strength, stability, and economy. Consequently the stronger, the more rigid, the more economical the structure, the more uncompromising and the more hopeless it seems to be in respect to beauty. The modern steel-girder or cantilever bridge, while, according to our present knowledge, it is perfectly adapted to its uses and functions, is in nearly every case an offense to the landscape in which it occurs. Its lines, since they have ceased to be structural curves, have become hard and ascetic mathematical expressions, and have not been brought into any sympathy whatever with the natural lines of the stream which it crosses, of the opposite banks which it connects, of the meadows, forests, and mountains among which it is placed. All sylvan effects of harmony are shocked by its discordant intrusion. The vast aqueducts of the Romans, the arched bridges of stone, the catenary curves of the modern suspension bridges with their high towers, and some forms of bridges constructed with bowstring girders, are more or less affiliated with the natural conditions, so that they give no shock, save frequently of pleasure at their expression of grace and fitness. But we are assured that these structural forms are obsolete or are becoming obsolete, and that the straight bridge-truss spanning from pier to pier, the cantilever overhanging the perilous abyss, the pivoted draw-span, all constructed with cold geometrical precision, with hard, unfeeling lines of tension and compression, have taken their place, to the great advantage of the railroads and the greater security of the public. It is in vain that the conscientious engineer occasionally attempts to compromise with grace by ornamenting

his intersections by rosettes or buttons of cast iron, or by rearing a sort of arch or portal of triumph at the entrance to his bridge with a lavish display of metal shell-work, scrolls of forged iron, and tables cast and gilded with names and dates. But the compromise comes too late; the main essential lines cannot be condoned by afterthoughts of this sort; and as far as the eye can see, these lines, though they may satisfy the reason, generally affront the sense of beauty.

"Now it seems to me important to note that the methods of nature always culminate in infinite expressions of beauty, and that beauty is an essential part of the principles of natural growth. The Great Creator never makes anything, animate or inanimate, ugly in making it strong or swift or durable, or in fitting it to the economy of nature. Grace is a part of the system of creation. Is it reserved for man in his secondary creation to make things unlovely in proportion to their complete and perfect adaptation to the satisfaction of his practical needs? Is this difference significant of some quality which is wanting in our science?

"But, it may be said, if a steel-trussed bridge, economically and wisely constructed according to our present light, offends our ideals of grace and beauty, the fault perhaps is not in the structure, but in the rigidity and immobility of the ideals which have been established by conditions long since outgrown in the progress of science. The attempts of the English bridge-builders in iron in the early part of the century to meet these old ideas resulted in constructions which, though they may satisfy the eye of the artist, and combine more or less gracefully with the landscape, are uneconomical and unscientific. The principles of structure involved are incorrect, and unnecessary expense was incurred in forcing into the design features conventionally acceptable, but which had nothing to do with the structure. and which in fact were a hindrance to it, concealing rather than illustrating it.

"The architect will not find it difficult to agree with his brother, the engineer, that a mask of ornamental cast iron, covering the essential features of the structure in order to force upon it an effect of grace, is illogical in the extreme. Indeed, a great modern master of architecture has laid down the axiom: 'A form which admits of no explanation, or which is mere caprice, cannot be beautiful; and in architecture, certainly, every form which is not inspired by the structure ought, therefore, to be rejected.' The conscientious modern architect aims to shape his design according to this reasonable limitation, and he has been thereby enabled to produce occasional effects of beauty without imposing on his composition a single idea which is not suggested either by the structure or by the use of the building. Even a factory, a gasometer, a railway shed, an elevator, need not challenge the architect in vain to produce effects of fitness not entirely inconsistent with the requirements of art. Indeed, the engineer himself, with axioms or maxims of art, has, in the evolution of the roof-truss, the locomotive, and many industrial machines, succeeded in satisfying ideals of beauty in the very process of making them powerful, compact, and economical of material and space. The modern steel-armored war-ship has already, in this early stage of its rapid development, substituted for the ideas of maritime beauty, speed, and strength which prevailed in the time of Nelson and the other great historical admirals, and which were celebrated in the songs of Dibdin and Campbell, an entirely different ideal, hardly less imposing, though as yet without poetic recognition. But the evolution of the steel-trussed bridge has as yet satisfied neither old ideals of beauty, nor has it made new ideals. Its essential lines are drawn in apparent disregard or contempt for grace of outline or elegance of detail. The difficulty seems to be inherent in the present approved structural system of designing horizontal, straight, open-trussed girders or cantilevers, resting on rigid vertical piers of masonry or iron, without regard to any other considerations excepting those of statics. The eye requires to be satisfied as well as the trained intelligence, and demands not only grace of proportion, but a certain decorative emphasis expressive of especial functions. The primitive post and lintel structure of stone was as hopeless, apparently, as its modern derivative, the steel-trussed bridge, until the Greeks, with unerring instinct of art, con-

verted it by perfectly rational processes into that ideal expression of beauty which is known as the Doric order. This Doric order is a structure which depends less upon subsidiary decoration than upon proportion for its unparalleled success as a work of art. The Parthenon would still be lovely without the sculptures of its friezes, metopes, and pediments. Its columns, reduced to dimensions which encumber them with no useless brute mass of material, were so treated with entasis, capital, and fluting as to express exactly members in vertical compression; its lintels were so subdivided as to draw attention to, and to illustrate, all their functions in the structural scheme. They contained no features of caprice or fancy. Now the essential qualities of the steel-girder bridge differ from those of the post and lintel of the Greeks because, in the former, the structure of the lintels permits of a wider spacing of the posts, and the posts have assumed the dual function of piers for vertical support and of buttresses to withstand the horizontal pressures of the stream in which they are built; the lintels, in their turn, have lost their quality as compact, solid, homogeneous masses, have been resolved into distinct elements, and have become a complicated and highly artificial openwork contrivance of light steel members, which in their dimensions and articulations have been so combined in tension and compression as to produce a structure capable of sustaining without change of form not only its own weight between bearing points far apart, but that of moving trains, and of bearing without detriment vibrations and wind-pressures, and the expansion and contraction of its material by changes of temperature.

"These compound lintels or trusses are in themselves triumphs of mind over matter. At this moment they express a stage of evolution which has been in process for a century, and which doubtless will continue to develop in directions impossible to anticipate. They are structures not dedicated to the immortal gods, like the post and lintel of the Greek temples, the decorative character of which was largely inspired by religious emotions, but devised to meet secular and practical conditions of an exceedingly unpoetic and unimaginative character. The mind of the architect appreciates the fine economy of these sensitive and complicated organisms, but it also recognizes that they are still in active process of development; that they are on trial, and will not reach final results until they shall have assumed those conditions of grace and beauty which are essential to completion. It is evident enough that all the features of perfection in animals have been very gradually evolved, by survival of the fittest and by adaptation to use, from the awkward and monstrous shapes of the antediluvian period; that geological erosion and drift have clothed the naked rocks with beauty; and that the whole vegetable creation has been improved by art. Nature herself is not contented with inelastic dogmas. In like manner, the locomotive, the steam-engine, the modern war-ship, have all become objects of awful beauty, not because of the imposition of unnecessary features, but because of the natural and reasonable growth of their essential structure.

"If, therefore, the ugly character of the present steel-trussed bridge is in itself a proof of the immaturity of the science which has produced it, the remedy, of course, must reside in the perfecting of the science, and this process of perfecting will be quickened, if beauty is recognized in engineering as it is in architecture, as an aim and not as an accident of growth. The architect guides and hastens this progress towards the perfect type by fundamentally composing his structure with a view to an agreeable proportion of its parts; in detail he studies to emphasize the special and important points of his structure by a decorative treatment which shall indicate conventionally the character of the work accomplished at these points. It is true, perhaps, that the structural forms of materials with which the engineers have to work, especially in bridge-building, are hardly so elastic and manageable as those at the command of the architect even in his simplest and most severely practical problems; but it is none the less true that the training of the engineer leads him too often to an absolute disregard, if not contempt, for those refinements of proportion and outline, and for all those delicate adaptations and adjustments of detail, which, though perhaps separately slight, and apparently of small

importance, in combination tend to give distinction and a character of fitness and grace to works otherwise, from the point of view of art, rudely immature, basely mechanical, unnecessarily and insolently ugly.

"Mr. Henry James says that the French talk of those who see *en beau* and those who see *en laid*. The performance of the modern steel-bridge designers would certainly seem to place them in the latter category. It is not less certain that this result comes not from temperament, which is natural, but from training, which is artificial. The severe and absolute conditions in which the bridge-builders work do not prevent them either from great differences in manner and method of design, or from frequent and unnecessary extravagances of expenditure; but these extravagances are rarely, if ever, lavished in the services of beauty; because the cold and rarefied atmosphere of science and mechanical utility, in which they are accustomed to labor, has gradually frozen out the finer natural instinct which works for art and elegance in design. Beauty of proportion has often been proved by mathematics; but mathematics, when it has been allowed to be the only element in the development of a problem of construction has never accomplished beautiful results. Such results do not come by accident in any work of design, but by the liberal and generous observance of natural laws. The education, therefore, which from the beginning does not give some recognition to grace, proportion, elegance, as essential parts of construction, must be misleading and one-sided, and cannot lead to perfection. The recognition of these qualities, I am entirely persuaded, does not necessarily imply any sacrifice of practical accuracy in design or of mechanical precision in workmanship, nor need it affect materially that fine economy which is essential to perfection. Very sincerely yours,

HENRY VAN BRUNT."

From the foregoing letter we may gather by direct statement or by implication the following precepts:

1. A structure must be in harmony with its environment and not appear as an intrusion thereon.

2. Good general lines are first necessary as a basis, then a consistent scale or proportion of parts.

3. Mere ornamentation generally affronts the sense of harmony and fitness.

4. Methods of nature always culminate in expressions of beauty. Methods of nature also culminate in the survival of the fittest. Hence our conceptions of beauty have as a basis functional efficiency.

5. Owing to man's mental inertia, the rigidity and immobility of the ideals established by old conditions prevent proper recognition of the progress of science and of the needed modifications in standards.

6. A form which admits of no explanation, or which is mere caprice, cannot be beautiful. It must have and show some purpose in its general relation.

7. Each part of any structure should be treated in such a way that its function therein shall be apparent and emphasized according to the importance of that function.

8. Such emphasis may be attained by decorative treatment indicating conventionally the character of the work accomplished by the part.

9. Different kinds of material used in structures call for different treatment and varying æsthetic standards.

10. The present steel-trussed bridge is inherently ugly; but with the further perfecting of the science of bridge design, and a recognition of the fact that beauty is an aim and not an accident of growth, æsthetic forms will be evolved.

The underlying thought connecting these precepts is that the structure must be fitted for the work it is to do, that it should express the truth, and that imitations and falsities are vicious and outside the realm of rational æsthetics.

Let us proceed to consider more in detail the several precepts above formulated. To secure harmony between the structure and its environment means the merging of its general outlines with those of the landscape. In this connection, it should be remembered that the bridge will likely be seen from various angles, and that each view-point will cause its own individual impression. In case of conflicting impressions, it becomes a matter of good judgment as to which should control. The merging of outlines can usually be secured by attention to the approaches, by extending the hand-rails beyond the structure proper, or by curving the wing-walls of the abutments. A small arch or girder span can often be given dignity by lengthening the approach walls or hand-rails. An illustration of this is the Wabash Railroad Bridge over the main drive entrance to Forest Park, St. Louis, Mo., shown in *Engineering News*, Vol. LII, page 431. An example of the disregard of this principle is the arch at Multnomah Falls on the Columbian Highway, Oregon, in which an extension of the hand-rail on the right bank would have tied the structure into the ground and prevented the unpleasant feeling of abruptness that must inevitably strike the observer. This defect could readily be overcome by planting shrubbery in a mass at the end of the present hand-rail, thus permitting the structure to merge into the landscape.

The achievement of good general lines is best attained by a study of the profile of the structure.

There is no feature of a bridge so pleasing to the eyes of all observers, cultivated and ignorant alike, as perfect symmetry in the layout of spans; consequently it should be attained whenever practicable, even if some extra expense be involved thereby. Unfortunately, the conditions are not always favorable to perfect symmetry of design; for the bed-rock will often dip rapidly, and thus necessitate the use of spans of different lengths, and the channel of the river often refuses to keep at midstream, persisting in hugging one shore. In such cases it becomes necessary to do the best one can with the unfavorable conditions, and to make the structure sightly, if not symmetrical. If there be a draw-span on one side of the river, it is best generally to make all of the fixed spans alike. Should each successive span—because of the gradual shelving off of the bed-rock, and for the sake of economy—be made longer as the bed-rock deepens, the result will be unsightly, even if the increment of span length be regular, for the reason that to an observer there is no apparent motive for thus

diversifying the spans. Any divergence from symmetry and regularity for which there is a self-evident reason produces no unfavorable impression upon the beholder, although it may be sufficient cause for failure to excite his admiration for the structure. If one can see at a glance the *raison d'être* of all the principal parts and peculiar features of a bridge, his sense of fitness will be satisfied and his general impression will be favorable; but the nearer the approach to perfect symmetry and the more artistic the outlines, the more thorough will be his appreciation of the general effect of the structure.

The outline of a bridge should not be monotonously straight; nor should changes in outline be too abrupt, unless there is an apparent reason therefor, such, for instance, as a heavy intervening mass of pier. The best effects are secured by outlines changing by easy transition from one form to another. An example illustrating abrupt changes in outlines and lack of proper transition is that of the Chicago, Milwaukee and St. Paul Railway Company's bridge at Sixteen Mile Creek near Lombard, Montana, illustrated in Jacoby & Davis's book, "Foundations of Bridges and Buildings," page 450. In case of simple truss spans, a polygonal top chord giving the effect of a smooth curve adds much to the pleasing effect as well as to the economy. The harsh outlines of a cantilever bridge can generally be relieved by making the chords simulate a curve. Most cantilevers offend in this respect.

In proof of this statement are offered the layouts shown in Fig. 25*o* and 25*s*, representing two great Mississippi River bridges, viz., that at Memphis and that at Thebes. These constructions are inherently ugly. In respect to the latter structure the author made a competitive design on the basis of using simple spans of the same length as those of the cantilever bridge. He found the former layout to be no more expensive; and he is confident that it is much the more æsthetic, in spite of the fact that it did not win in the competition. It is illustrated in Fig. 52*c*, the central span having a length of 672 feet and each of the other spans a length of 522 feet. The former is simply a proportional enlargement of the others. It might have improved the appearance to make each end span 472 feet long and each span adjacent thereto 572 feet long so as to obtain a gradual increase of importance in spans from the end of the structure to the middle, as shown in Fig. 52*d*, but the governmental conditions did not permit. Moreover, the change would have increased slightly the total weight of metal, and the pound price would have been augmented a little because of the reduction in the amount of duplication. In the last figure it will be noticed that the proportional reduction process adopted for the submitted design has been carried into all four of the minor spans, and that the effect thereof is pleasing.

As further evidence that it is possible to make cantilever bridges æsthetic, there is shown in Fig. 52*a* a photographic study of the author's proposed bridge across the entrance channel to the Harbor of Havana,

Cuba. It is submitted that the outlines have a graceful appearance, and that the layout is quite economic, for the distance from centre to centre of main piers was fixed by local conditions, and it was found advisable to make the suspended span as long as practicable in order to provide a wide opening for the full clear headway. The leading dimensions of the proposed structure are as follows.

Main opening from centre to centre of piers......	808 feet
Length of suspended span......................	400 feet
Length of each cantilever arm..................	204 feet
Length of each anchor arm.....................	200 feet
Vertical clearance above water at mid-span.......	196 feet
Ditto at ends of suspended span................	190 feet
Width of main roadway........................	42 feet
Width of each sidewalk........................	8 feet

Grades in each direction to middle of suspended span, 5 per cent.

Attention is called to the spiral approach, which is described in Chapter XLV.

Attention is called also to a novelty in the picture shown in Fig. 52*a*, for it represents the structure as it will really appear after completion. The way this effect was obtained was as follows:

There was purchased from a Havana photographer a long panoramic photograph of the city, the harbor, and the adjacent vacant land on the left-hand side of the channel as one enters; and the camera position of the picture was marked on a plan of the location and of the bridge, a profile of the latter being also shown on the same sheet. A thorough study of the principles of panoramic perspective made it possible to construct the picture of the bridge and its approaches on the large photograph, which was afterward reduced. The result was so successful that many people have been deceived by it, thinking for a while that the photograph was taken from the finished structure. Of course, a careful examination of the picture will quickly show the incorrectness of such a first impression. In the preparation of this picture the author was aided by Señor Horacio Hevia, a young Cuban draftsman, to whose good taste and ability is due the satisfactory style of its finish.

This device can be used to great advantage in studying the æsthetics of any layout, for it enables one to determine how the completed structure will actually look.

The last design of the Quebec Bridge submitted by the commission of engineers is inferior in æsthetics to the design of the structure which failed, as the chords of the former are in straight lines which intersect each other abruptly. The ends of the structure also offend the eye by their abrupt termination. By making some slight changes in the outline it would have been practicable to improve greatly the appearance. Com-

paring that design with the design of the proposed New Orleans Bridge, by Dr. E. L. Corthell, C. E., as illustrated in Fig. 52*b*, one is struck by

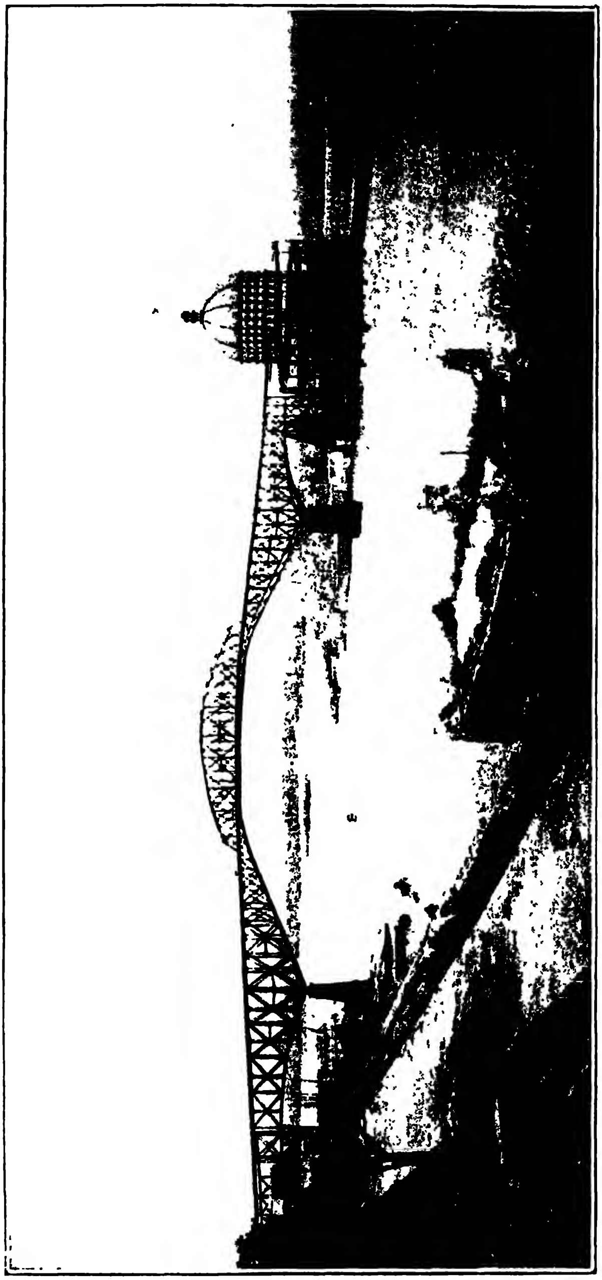


FIG. 52*a*. Proposed Bridge Across the Entrance Channel to the Harbor of Havana, Cuba.

the superior appearance of the latter. It is true that the main span is much shorter, being only one thousand feet long as against eighteen

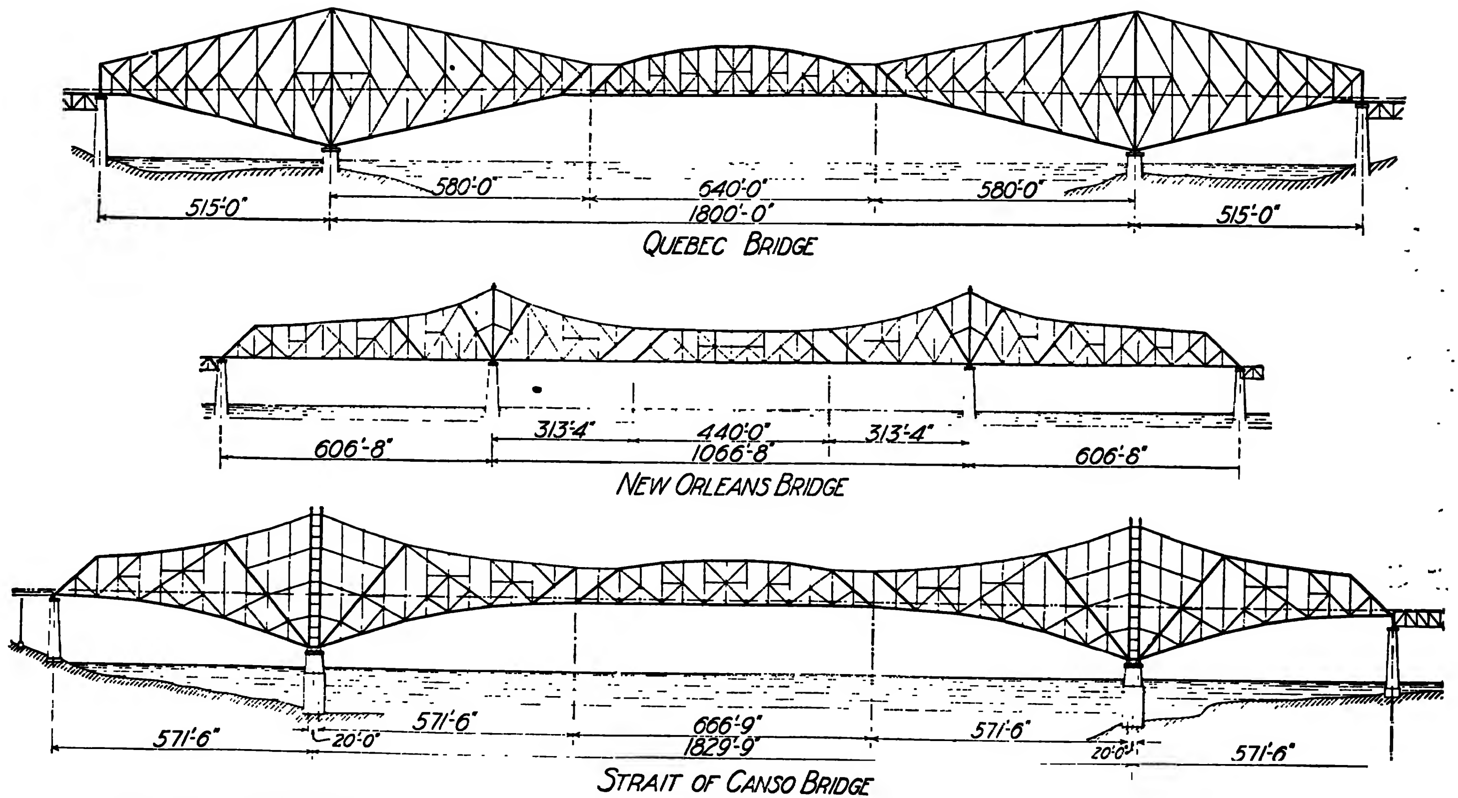


FIG. 52b. Contrasted Layouts of the Quebec Bridge, of the Proposed Bridge over the Mississippi River at New Orleans, and of the Proposed Bridge over the Strait of Canso in Nova Scotia.

hundred feet in the Quebec Bridge, nevertheless that does not militate seriously against the legitimate drawing of a comparison of the æsthetics of the two structures.

In 1904 the author made a study, with full detail drawings and estimates of cost, for a proposed single-track, cantilever railway bridge, designed for future double-tracking, across the Strait of Canso, Nova Scotia. The main span was eighteen hundred and thirty feet long—just thirty feet longer than that of the Quebec Bridge. In the author's design the feature of artistic appearance was given full consideration, and the layout was made as æsthetic as the limitations of his personal experience and taste permitted. In order that the reader may compare for himself the three layouts mentioned, they are reproduced and shown together in Fig. 52*b*.

In many bridges what would otherwise be a pleasing outline is spoiled by the introduction of massive ornamental portals at the ends and intrusive towers at the intermediate piers. European bridges offend in this respect more than American structures. Examples of this are the Tower Bridge at London, the Rhine Bridge at Mainz, and the Worms Highway Bridge over the Rhine. A comparison of the general lines of these bridges with those of the Brooklyn Bridge, the Eads Bridge at St. Louis, the Chestnut Street Bridge over the Schuylkill River at Philadelphia, and the Washington Bridge over the Harlem River in New York City, results greatly to the advantage of the American designs, mainly because of their simplicity as contrasted with the over-ornamentation of the European structures.

It is not permissible to correct the hard, rigid outlines of a span by the use of additional parts which falsely proclaim a different function for the members or confuse their action in the structure. An illustration of an offense of this nature is that of the New York Central Railroad Belt Line Bridge over Colvin Street in Buffalo, N. Y., as illustrated on page 404 of Jacoby & Davis's "Foundations of Bridges and Buildings." There the attempt was made to give the plate girder spans something of an arch effect by introducing elongated curved brackets below the lower flanges of the girders and adjacent to the posts. The falsity of this construction is made conspicuous by the continuation of the lower flange angles in a straight line over the full length of the girder. A further offense to the eye occurs in the lightness of the tapering columns for arch construction and their evident insufficiency to withstand the bending that such construction would put on them when the bridge is partially loaded.

In addition to adopting a pleasing outline or profile for the bridge, attention must also be paid to the scale or proportion of the parts. That is, the parts should bear a harmonious relation to each other and to the whole, and should appear to be of the same conception and not as if they were details taken from other structures and illogically fitted together. In this connection it must be recognized that habit plays an important

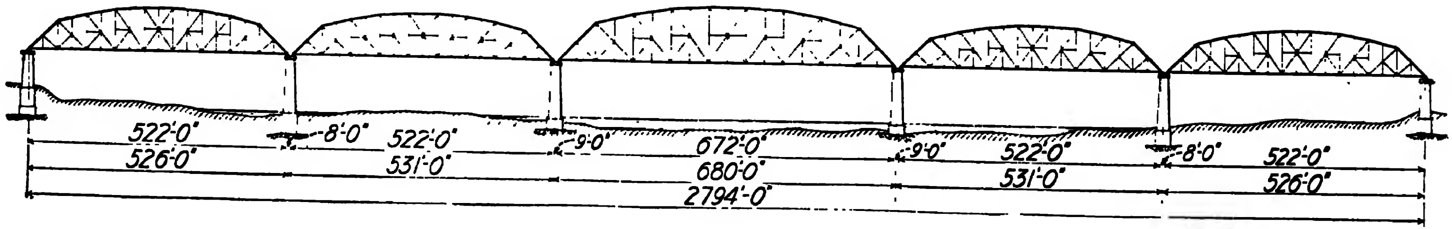


FIG. 52c. Proposed Bridge over the Mississippi River at Thebes, Ill.

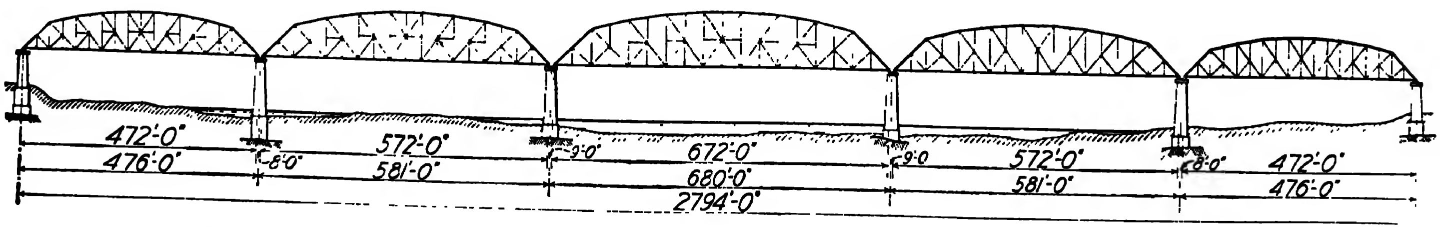


FIG. 52d. Alternative Layout for Proposed Bridge over the Mississippi River at Thebes, Ill.

part in our conception of proper scale or relation of things. Those proportions which by long usage we have become accustomed to we regard as fitting and pleasing; so that a departure from such recognized standards is often confusing and disappointing. This sense of scale is conventional and is acquired. When a new structural material with different physical properties is introduced, a scientific and consistent use of it offends our preconceived idea of scale and proportion, until we have become habituated to its rational utilization and thus have modified our former conception of harmonious proportions. This again brings us to the question of whose eye the engineer should strive to please. Is it the eye of the man looking backward to the old order of things, or the eye of the man anticipating the approaching phase of evolution and attempting to adjust himself and his standards to the coming innovation?

Ornamentation can have no other justification than that it serves to render clear or to emphasize the function of a member in the structure. Distinction must be made between appropriate and inappropriate, necessary and unnecessary, and expensive and inexpensive decoration. For instance, while it is always proper to adapt the lines of a structure to the production of the most graceful effect, provided that in so doing no sacrifice of constructive excellence be thereby involved or extra expense incurred, it would often be injudicious to expend money on pure decoration. The builder probably cannot spare the money, and the location of the structure may be such that any extra expense for ornamentation would be absolutely wasted. If a bridge is to be located where it will be seen constantly by many people, it is well to spend extra money to make it sightly, beautiful, and in keeping with its surroundings; but when it is to be placed in a dense forest or on a sandy desert where it would seldom be seen, it would be folly to spend any more on its construction than is called for by the engineering requirements of the conditions, due allowance being made, of course, for a possible peopling of the forest or desert in the not very distant future. Many European bridge designers have been guilty of violating this economic consideration.

Functional efficiency—the ability of any member or detail to perform the duty assigned it in an efficacious way—is a most valuable criterion. If any part can be rendered more efficient by a modification, then such a change is to be made. It may mean that our æsthetic standard will require some readjustment, but the ultimate outcome will be a harmonizing of that standard with the attainment of maximum efficiency. Take as an example the case of curved struts. There have been advocates of such, and even users thereof, in large and important bridges; yet to the mind trained in stress analysis this is a monstrosity not to be tolerated. As a better understanding and greater appreciation of the principles of mechanics come to the layman, a change in his standard will take place. This brings us once more to the question of whose eye the engineer should attempt to satisfy.

The introduction of unnecessary parts or forms that have no apparent or sufficient purpose or connection with the structure is to be avoided. These detract from the fundamental objective. An example of the violation of this principle is the Tower Bridge of London. This case has been well set forth by H. Heathcote Statham, Esq., Fellow of the Royal Institute of British Architects. The following quotation is made from his paper on "The Architectural Element in Engineering Works," published in the Journal of that society of May 20, 1899.

"The Tower Bridge is an example of a different kind; it represents the vice of tawdriness and pretentiousness, and of falsification of the actual facts of the structure. It is stated that the exterior clothing was designed by an architect; he cannot have been a very eminent one, as we never hear his name; it looks to me more like what results from the advertisement we sometimes see —'Wanted immediately a draftsman; must be an expert Gothic hand'—it is draftsman's architecture. The exceedingly heavy suspension chains are made to appear to hang on an ornamental stone structure which they would in reality drag down, and the side walls of the apparently solid tower rest on part of the iron structure, and you could see under them before the roadway was made up. All architects would have much preferred the plain steel structure to this kind of a sham. The same kind of spirit is showing itself in the treatment of ironwork; capitals inserted where they have nothing to do with the structure, spandrels filled in with bad Gothic tracery, and so on. If iron is designed on good lines, it will look better in itself without these gewgaws. We could not have a better example of this than the *Galerie des Machines* at Paris; an iron-roofed structure on the grandest scale, in which there is not a particle of decoration, and yet which is so fine and imposing in its effect that it deserves to be called a great work of architecture as well as of engineering."

The author, who has seen and examined thoroughly the Tower Bridge, endorses unequivocally these strictures of the eminent British architect; and in addition he would state that, in his opinion, the structure has the honor of being the most monumental example of extravagance in bridge construction in the world. For but a small percentage of the entire cost of the bridge a far better and more effective structure could readily have been built. Any American engineer travelling in England would do well to visit the bridge so as to see for himself how far in that country extravagance in design can be carried and to what an extent the important factor of efficiency can be ignored. Many other European bridges fail in respect to æsthetics because of inappropriate ornamentation, such for instance as exaggerated portals highly bedecked with trimmings that outrage good taste.

The discussion of this last principle leads by antithesis to the next one. If it is undesirable to have superfluous members or parts, then, on the other hand, those parts which are necessary should have that necessity made apparent by receiving such treatment as will fittingly proclaim their function and importance in the construction. Many structures otherwise satisfying fail in this respect, especially those of masonry and concrete. The introduction of reinforced concrete of late years has given an impetus to the building of arch spans, a type of structure that

admits of æsthetic treatment far more readily than do truss spans. Many arches fall short of their best effect just because sufficient attention has not been given to this principle of making evident the function and relative importance of each part of the structure. Their usual defects are as follows:

Failure to define the arch ring by letting it merge into the spandrel walls without any paneling for relief.

Failure to define the skew backs or springing lines of the arch.

Failure to separate the spandrel wall from the handrail by a belt course conforming with the grade of the roadway.

Failure to subordinate the handrail to the main part of the structure.

Failure to give the piers distinctiveness and the ignoring of the fact that the more important part of the pier is below the spring line.

The main portion of the improvement in architectural effect in American bridge engineering practice which has taken place in the last decade (and it is by no means inconsiderable) has come through the extensive building of reinforced-concrete structures. The following examples, selected mainly from the author's practice, will serve to illustrate some of the progress in bridge æsthetics that has been made by reason of this comparatively new material, which adapts itself so readily to the production of forms pleasing to the artistic sense of the beholder—at least, more strictly speaking, they will show what the author has been striving to do in order to improve the appearance of his structures.

Fig. 52*e* shows a photograph of the Colorado River Bridge at Austin, Texas. It is situated on the main street of the city leading to the State Capitol. On that account it was urgent that the structure be made as sightly as the limited amount of the appropriation would permit. The said amount was $200,000; and as the bridge is one thousand (1,000) feet long and fifty (50) feet wide from out to out, and as the pier foundations were somewhat expensive, on account of troubles incident to hard foundation material, it was a difficult matter to keep the cost within the appropriation. This was just barely accomplished; hence there was no money available for ornamentation. Perhaps this was just as well, for the simplicity of the design is probably its most pleasing attribute—at least this opinion has been expressed by a number of persons whose taste is indisputable.

Fig. 52*f* shows a photograph of the Arroyo Seco Bridge in the City of Pasadena, Cal. In this case also the appropriation was small—too small, in fact, for several reasons. Curiously enough, the limit was exactly the same as that of the Austin Bridge, viz., $200,000; and no persuasion of the author's was effective in having the amount increased. It was questionable whether a proper structure could be designed so that the entire cost, including the engineering, could be kept within the limit, and to settle the question the author sent to his office an outline

of the design, with exceedingly full data for estimating the cost, and had a complete detailed estimate prepared. It showed that the work could

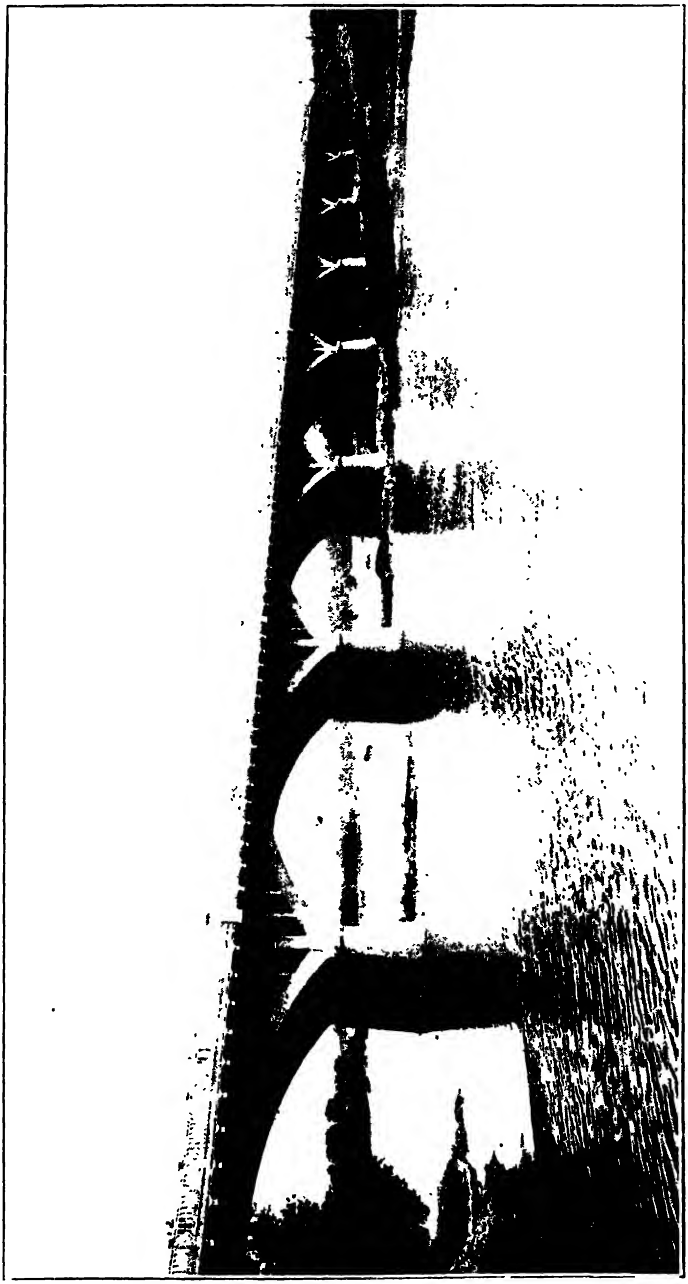


FIG. 52e. Colorado River Bridge at Austin, Texas.

be done with a possible margin of \$2,500; and in consequence, the author's firm was retained to design the bridge and supervise its construc-

tion. There was an unfortunate condition which governed the layout, viz., that if the structure were built entirely on tangent the crossing of the stream bed would involve either a much longer span or a deeper pier than would a location a short distance below, for the bed-rock curved suddenly in plan from a wide to a narrow gorge. The engineers of the city who had studied quite carefully the conditions before the author's arrival on the ground, had laid out the centre line of structure partly on tangent and partly on curve so as to avoid the wide portion of the gorge. The author objected most strenuously to this location, begging the mayor to arrange for the small increase of six thousand dollars, which his office reported as the estimated extra cost of the structure if built on tangent—but to no avail. As a last appeal he remarked: "Mr. Mayor, it is all very well for you to state that the people of your city understand the reason for building the structure on curve; but in the future when intelligent people view the bridge they will exclaim 'What kind of a city engineer did they have, what kind of a consulting engineer did they have, what kind of a mayor did they have to permit of such a violation of sound engineering principles as to build a structure on a curve when it could have been shortened and, therefore, cheapened by laying it out on tangent!'" To this the mayor replied: "I know it, but I cannot help it. We must build the cheaper structure." Unfortunately, the real reason for the peculiar layout is hidden from sight, as the rocky sides of the deepest part of the gorge are covered with débris.

The bridge was built by contract and just within the limit of the appropriation. Everyone is delighted with its appearance; and, strange to say, one of the principal features of the structure to which the inhabitants of the city point with pride is the graceful curve at its eastern end. However, the author was right when he made his final appeal to the mayor, for on several occasions lately when visiting in California, and especially once when lecturing to the engineering students of the State University, he was asked by certain observing persons to explain the *raison d'être* of the curve in plan. Notwithstanding this unavoidable flaw in the structure, the conditions of the surrounding scenery are so favorable to the development of æsthetic construction and the study of the layout was so effectively made that residents and visitors alike are unanimous in their approval of the appearance of the structure. From an engineering standpoint the author wishes to put himself on record to the effect that while the entire bridge is designed and built in strict conformity with the best engineering practice, the live loads provided for are small and the spans were not figured for carrying electric railway traffic, and are not capable for doing so without overloading. It is true that the city authorities desired to keep the car lines away from the bridge for all time and to use it solely for pleasure driving; but the day will probably come when some ultilitarian administration will want to run cars over the bridge, and they may even decide to do so in spite of the fact that it was not designed to carry such heavy loading.

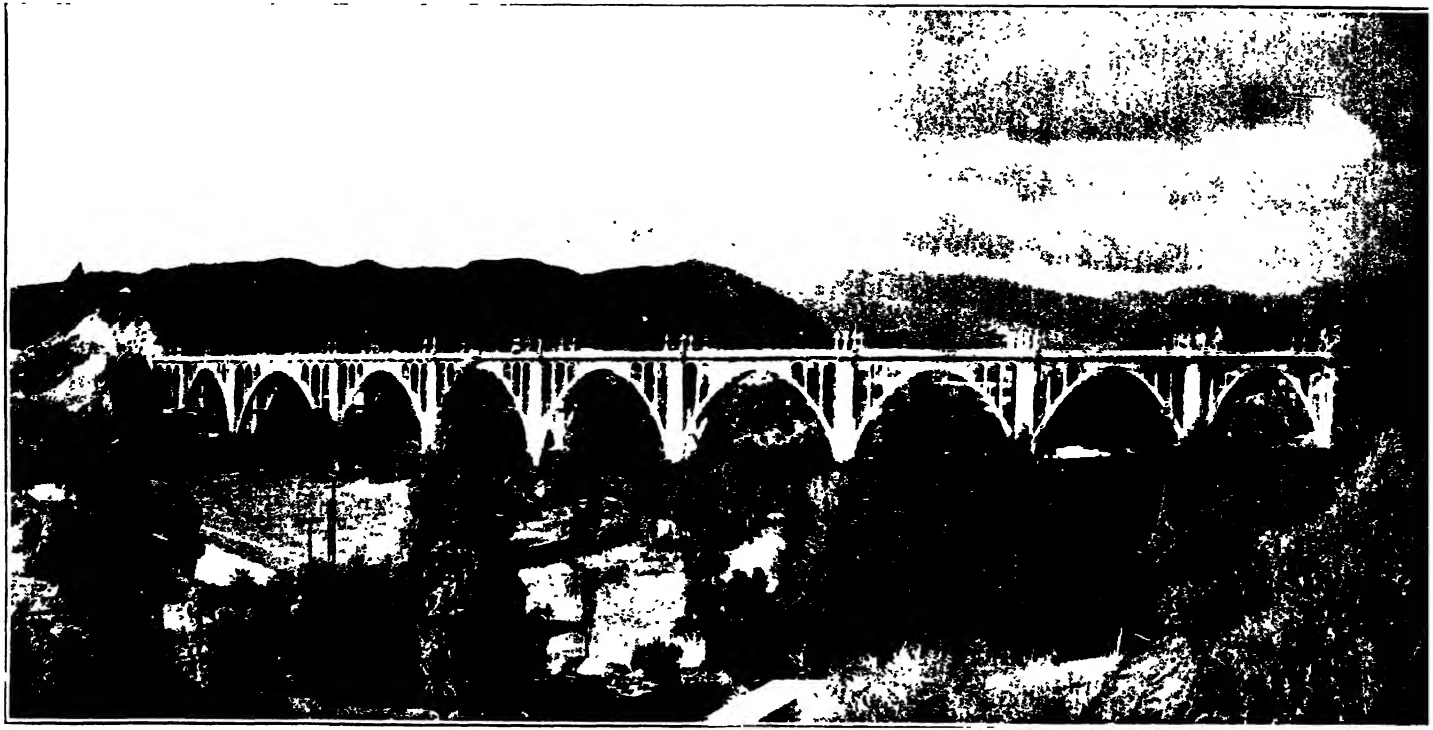


FIG. 52f. Arroyo Seco Bridge at Pasadena, Cal.

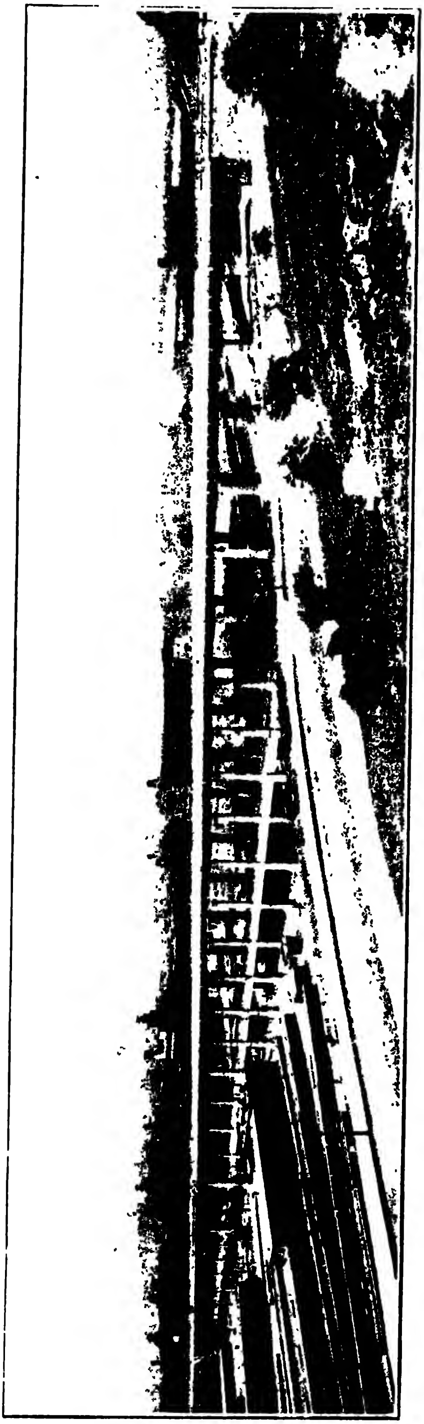


FIG. 52g. Twelfth Street Trafficway Viaduct at Kansas City, Mo.

FIG. 52h. Capitol Avenue Bridge over Fall Creek at Indianapolis, Ind.

Fig. 52*g* shows a photograph of the Twelfth Street Trafficway in Kansas City, Missouri, lately completed, the engineering having been done by the author's firm. Two studies were prepared, one involving a layout of true arches, and the other a layout of girders ornamented by curving slightly the bottom chords, as shown in the photograph. Both the author and his partner preferred the arch layout, notwithstanding that its æsthetic effect was somewhat marred by the existence of the lower deck; but the other design was adopted by the city authorities not only on account of the somewhat smaller expenditure involved but also because

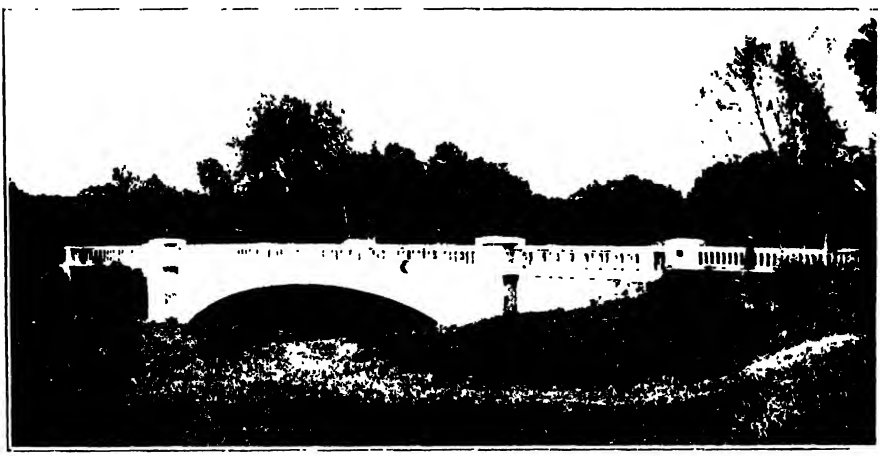


FIG. 52*i*. Wornall Road Bridge over Brush Creek at Kansas City, Mo.

its appearance pleased them better. The lines of the arch design were certainly the more classic, but the slightly curved bottom chords of the girders, in spite of the falseness of their function, certainly have a most pleasing effect.

Fig. 52*h* shows a photograph of a very artistic reinforced concrete bridge, covered with a veneer of cut stone, located over Fall Creek on Capitol Avenue in Indianapolis, Ind. It was designed by Robert C. Barnett, Esq., C.E., under the supervision of the eminent landscape engineer, George E. Kessler, Esq., C.E., to whom the fine artistic effect of the bridge is mainly due.

Fig. 52*i* shows a photograph of a small reinforced concrete arch bridge on Wornall Road over Brush Creek in Kansas City, Missouri. It was designed by the author's firm for the Park Board, and has a most pleasing appearance and appropriate setting.

Fig. 52*j* shows a photograph of the Tunkhannock Creek Viaduct, built by the Delaware, Lackawanna, and Western Railway Company at Nicholson, Pa., on a 43-mile relocation of a portion of the line between Scranton, Pa., and Binghamton, N. Y. As this is the largest railroad viaduct of its kind in the world, a detailed description of it will be given, the

data therefor and the photograph having been furnished through the courtesy of G. J. Ray, Esq., C.E., the Chief Engineer of the road.

It is a double-track bridge, 2,375 feet long, 240 feet high above the creek, and 34 feet wide from face to face of parapet walls. All piers are carried to bed-rock, which is reached at depths from 10 to 100 feet below the surface of the ground, making at the deepest pier a difference of 300 feet in elevation between bed-rock and top of rail. The viaduct consists of ten 180-foot and two 100-foot full-centered arches, the latter being abutment arches. The main arches are divided into two parallel ribs, each 14 feet wide and 6 feet apart; and the crown thickness is 8 feet. Each arch is surmounted by eleven 13′ 6″ transverse spandrel arches. They carry two reinforced concrete parapet walls, each 3 feet thick and 4 feet above the top of rail, for the protection of derailed trains. The abutment arches are also built in two ribs. A floor system similar to that of the main arches is continued to the centre of each abutment span. The heavy approach fill covers the other half and slopes through the hollow superstructure, completely concealing the abutment arch, yet the fill does not come upon the back of the last main arch.

Considerable thought was given to the architectural features of the design. The 4′ 3″ centering ledge was covered with steps and paneled after the centre was removed. Panels were also placed in the parapet walls and pilasters were used to relieve the otherwise plain surfaces. The piers were scored to hide the horizontal construction joints. The scoring is spaced 4 feet apart. Each 4-foot lift contains 235 cubic yards of concrete which was run in one operation.

The viaduct contains 167,000 cubic yards of concrete and 2,300,000 pounds of reinforcing steel. The volumes of the earth and rock excavations for the piers were 40,000 and 3,500 cubic yards, respectively. Work on the viaduct started in August, 1912, and required three years for its completion.

Too much cannot well be said in praise of the artistic effect of this great structure. The immense size of the bridge, the massiveness of the entire construction, the perfect symmetry of the layout, the exact similarity of the numerous spans, the complete semi-circles of the arches, and the harmonious effect of the superimposed detailing all appeal forcibly to the æsthetic sense of the trained bridge engineer; and the impression produced upon the mind of the layman cannot fail to be truly satisfying.

Among the author's most successful studies of æsthetics in steel bridge construction are the two New Zealand arches and the Fraser River arch of the C. N. P. R. R., described in Chapter XXVI and shown respectively in Figs. 26*k*, 26*i* and 26*j*. It is undeniable that the arch is the most artistic of all types of bridges, for its graceful lines are always pleasing. It is to be hoped that as time passes American engineers will make a practice of adopting it for all crossings where it is suitable.

The advent of new material with different physical properties from

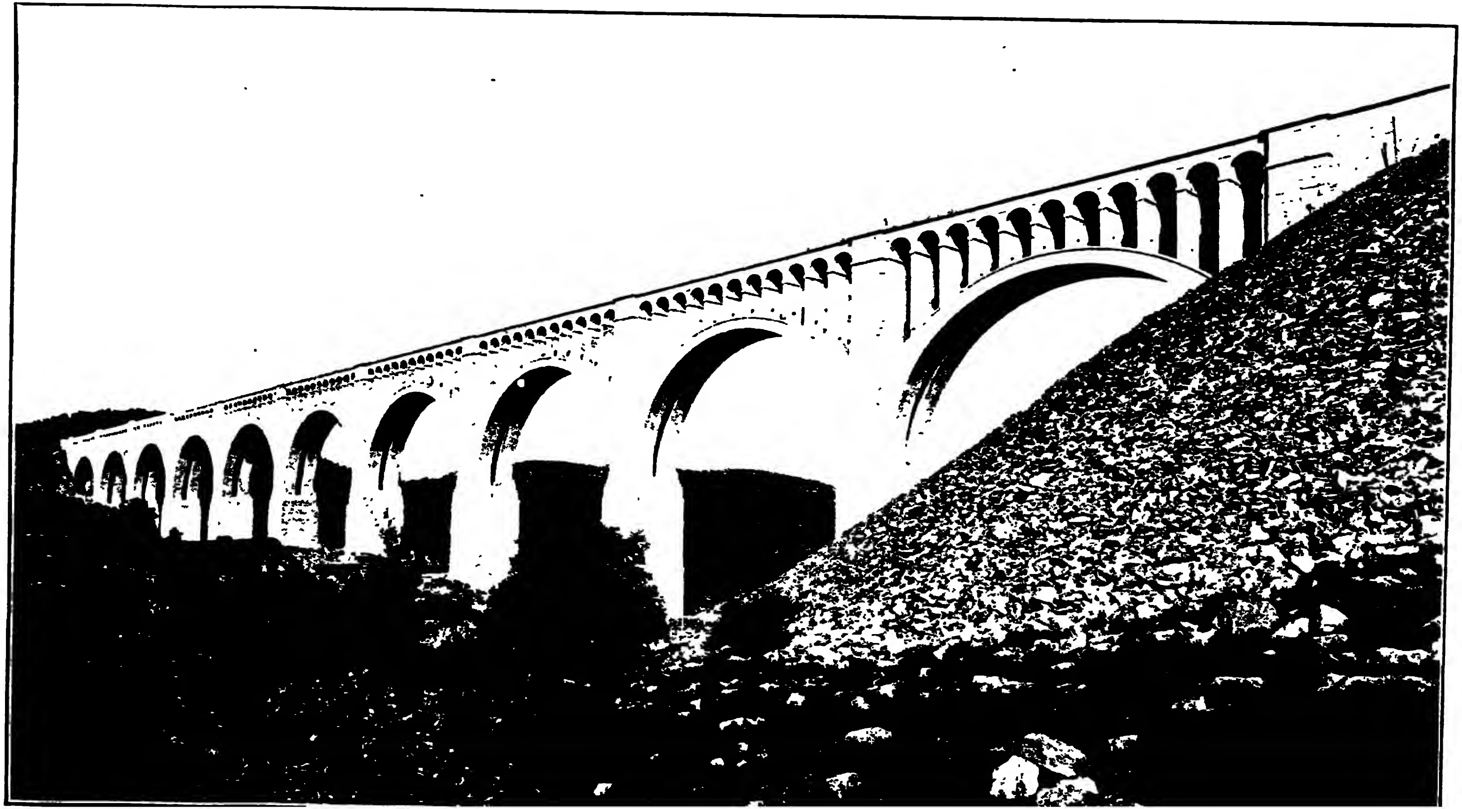


FIG. 52*j*. Tunkhannock Creek Viaduct on the Delaware, Lackawanna and Western Railway.

those customarily used places the designer in the need of a new standard of æsthetics. In developing such a standard, the fundamental criterion of fitness will be that of attaining the highest functional efficiency and employing it in the appearance of the entire construction. When this is attained, the old standards will gradually be made to conform to the new conditions.

In suggesting that "if a steel trussed bridge, economically and wisely constructed according to our present light, offends our ideals of grace and beauty, the fault perhaps is not in the structure, but in the rigidity and immobility of the ideals which have been established by conditions long since outgrown in the progress of science," Mr. Van Brunt has probably indicated the lines of convergence of engineering practice and architectural ideals; for while, as before stated, much can be done with most bridge designs to improve them without increasing their cost or affecting their efficiency, on the other hand, it is often impossible for an engineer to modify a bridge design so as to meet fully the critical objections of a good architect without introducing features both faulty and expensive. However, it must not be inferred from the foregoing that the author is defending the many bridge designers in their indifference to the artistic in construction. He believes that the preceding letter of Mr. Van Brunt's gives a very just and unprejudiced statement of the status of affairs at the time of its writing. But of later years more attention has been given to æsthetics in bridge design; and the author feels that some progress in artistic bridge construction has been made.

In 1897 the author wrote thus in *De Pontibus:*

"The principal hindrance to the progress of æsthetic reform in bridge-building is liable to emanate from the bridge-manufacturing companies, who have been so accustomed to submitting competitive designs, and who have made in the past so much money thereby, that they will naturally consider any fundamental innovation of this kind as detrimental to their interests. Nevertheless, when some concerted action on the part of bridge specialists is inaugurated with the object of making bridge structures more sightly, it is probable that the manufacturing companies will be far-sighted enough to recognize that their true interests will not be subserved by offering any serious opposition to the proposed reform. Some obstruction is likely to come from managers of railroads, who have for years been used to buying their bridges as cheaply as possible without any regard to appearance, and too often with very little in respect to constructive excellence. It will devolve upon the chief engineers and the bridge engineers of railroads to influence the managements of their lines so as to incline them towards a more favorable consideration for appearance when deciding upon the designing and purchasing of their bridges.

"But the moulders of public opinion in respect to the necessity for a due consideration of architectural effect in bridge-building must, of necessity, be the independent bridge engineers of the country, who are not so much influenced by monetary motives as are engineers connected with railways and bridge companies, although it must be confessed that some of the most prominent bridge specialists are the greatest offenders against the principles of æsthetics.

"There is a general impression among engineers that to ingraft architectural effects upon bridge construction will always involve the necessity for an increased expenditure

of money; but this notion is incorrect, because there are many large and important bridges in the United States which could have been beautified, and at the same time cheapened, without in the slightest degree impairing their strength, rigidity, or efficiency, by simply modifying their harsh and uncompromising lines. It requires the expenditure of more thought than money to obtain an artistically designed bridge; for a little money will go a long way in producing a decorative effect upon such a structure.

"The author is a firm believer in the principle that true economy, engineering excellence of construction, and the best architectural effect will almost invariably be found to accompany each other, and be inseparable in the designing of any bridge. Moreover, any bridge built with due consideration for, first, efficiency, second, appearance, and, third, economy, will be satisfactory and gratifying to not only the trained expert, but also to the general engineer and railroad man, and even to the public; because when an observer notes that in such a structure all the engineering requirements are properly provided for, that there is no evident waste of material, and that all due advantage has been taken of the conditions to render the bridge sightly and in harmony with its surroundings, his eye will of necessity be pleased, and his inherent sense of fitness will cause him to regard the structure with a feeling of pleasure.

"To recognize and acknowledge the deficiencies of modern bridge designs from the artistic point of view is one thing, but to show how they are to be remedied is another; because, while it is easy to say that a certain structure does not come up to one's ideal of grace and beauty, it is very difficult to show exactly where the defects are, and what should or could be done to remove them."

Notwithstanding this, the author believes that the fundamental precepts previously enumerated, if followed consistently, will eliminate the most glaring sources of ugliness in bridge designs. To secure positive and satisfactory results in the decorative architectural details is more difficult, as that is a matter requiring special training; and, therefore, it cannot well be done through mere instinct.

In making a study of the æsthetics of a bridge design, after determining what spans are applicable, it is well to make one or more layouts on a large scale on the brown paper that is used in engineers' offices for pencil-drawings, indicating the circumscribing lines of all main members to scale, and tinting or filling between the said lines with pencil-shading; then tack the paper on a wall, and stand off at various distances to judge the effect. By doing this one can form a very correct opinion concerning the comparative merits of several layouts, and can ascertain where and how any particular layout can be improved. A consultation with several members of one's office force upon the architectural features of the various designs will often result in an improved effect; for nothing else will bring out both the favorable and the unfavorable characteristics of a plan like discussion. In the outlining of each span a great deal can be accomplished toward beautifying a structure, and there is no better way to study the general effect of any proposed outline than the one just indicated, viz., laying out various trusses to scale, tacking the paper to a wall, and criticising them. It will surprise any one who tries this method to see how quickly he can detect the slightest variation from correctness in outline, and what a difference in effect even a small change

in a truss depth will produce. It was in this way that the trusses of the author's bridge over the Missouri River at East Omaha were proportioned; and it is doubtful if any improvement could be effected in their outlines when all the factors involved in the question are duly considered, for Mr. Van Brunt gave his unqualified approval of the architectural effect of these outlines. In this problem there were but three points to determine, viz., the depths of truss at the two hips and the depth at the tower, for the number of panels was settled by economic considerations, and the

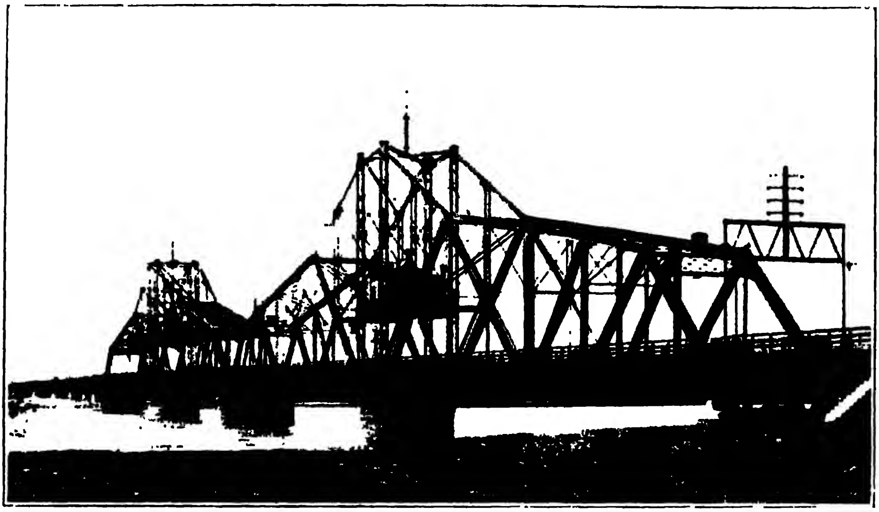


FIG. 52*k*. Swing Spans of the Missouri River Bridge at East Omaha, Neb.

straightness and section of the top chords were necessitated by certain questions of efficiency. The depth at the outer hips was first determined by the requirements for clearance, rigidity, and appearance, then the depths at the intermediate hips and tower were settled by trial and discussion from the artistic point of view, due attention being paid to the engineering questions involved by the various inclinations of top chords and inclined inner posts. In Fig. 52*k* is reproduced a photograph of the long swing spans of that structure.

Fig. 52*l* shows an outline diagram of an alternative design for the movable span of the Pacific Highway Bridge at Portland, Ore., which is being engineered by the author's firm. In the bidding competition between this span and a vertical lift the latter was adopted on account of its superior economy and more satisfactory operation. The outlines of the swing span are good, although the author is of the opinion that those of the East Omaha swing are better.

By no stretch of the imagination can any bascule bridge be termed a thing of beauty. On the contrary, most of them are glaringly ugly, as can be seen by examining the various illustrations of Chapter XXX.

The lack of symmetry in a single-leaf bascule militates greatly against its appearance, and no addition of tower entrance or filigree construction can help it. The intrusion of an immense mass of concrete into the scenery is far from being artistic, and in most cases the counterweight has to be above the level of the deck. There is a condition, though, where the bascule construction can be adopted without much, or perhaps any, detriment to the æsthetics; but even in that case it cannot be said to add to the appearance, its effect being neutral rather than either posi-

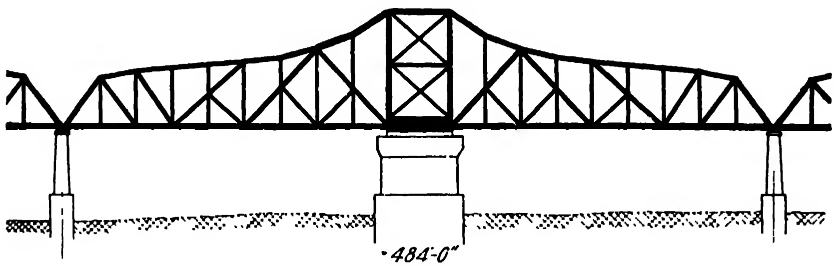


FIG. 52*l*. Layout of the Swing Span in the Alternative Design for the Pacific Highway Bridge over the Columbia River at Portland, Ore.

tive or negative. The condition is that of a fairly low, highway, deck structure where the required clear opening is comparatively small. By using a double-leaf bascule with the bottom chords arched, keeping the counterweight entirely below the deck, and making all the fixed spans arches of about the same span length and general appearance as in the bascule, a good effect can be produced. In Fig. 52*m* is a layout of this type, being a study submitted a few years ago by the author to the City Engineer of Vancouver, B. C., for a proposed bridge over False Creek at Thurlow street. The bridge has not yet been built, but some day there will be a structure at or near that location, for the regular development of the city will necessitate one.

Nor is it an easy matter to fit a vertical lift span into a structure and obtain a fine architectural appearance; but the very magnitude and massiveness of the construction generally produce a pleasing effect upon the mind of the beholder, as do also the simplicity and the evident efficiency of the method of operation. A study of the illustrations in Chapter XXXI will convince one of the correctness of this assertion, and will prove to him that there is nothing inherently ugly in the vertical lift bridge as there is certainly in the bascule.

In determining the outlines of a span these few elementary principles are to be borne in mind:

First. There is nothing so ugly in a bridge as parallel chords unless it be a skew. However, for spans between one hundred and twenty-five feet and two hundred feet it is often best to use them, although in

certain cases where the loads are great it is practicable to adopt polygonal top chords for spans considerably shorter than the superior limit just mentioned.

Second. While it is generally economical of material to use very long panels, no such extreme length should be adopted as would involve an awkward appearance due to flatness of diagonals.

Third. The curvature of the top chord should be made as great as is consistent with a proper consideration of web stiffness and counterbracing.

Fourth. When it is practicable in Petit trusses to curve the top chord to such an extent as to make too small the inclination of the endposts to the horizontal, it is permissible to let the latter extend over one panel only and to make all the main diagonals extend over two panels. The effect is ungraceful, however, when the main diagonals occupy one panel each near the ends of the span, and two panels each elsewhere.

Fifth. When appearance alone is in question, trusses very deep at mid-span are desirable; but an excessive truss depth is conducive to a reversion of bottom-chord stress by the wind load--a condition which has either to be avoided or provided for by stiffening the bottom chords. In extremely heavy bridges, especially where the dead load is unusually great, it is possible that an undue consideration for economy of metal might cause a designer to adopt a truss depth which would be actually too great for appearance, but this is not likely to occur very often because of other limiting conditions.

Sixth. There are certain limiting relations between width of bridge, depth of truss, and length of span which, for the sake of good effect, ought not to be exceeded. Usually the rules established on account of purely engineering questions will prevent these limits from being transgressed, thus proving a maxim which the author has often maintained, viz., that in any design any violation of engineering principles is also a violation of good taste from an artistic point of view.

Seventh. A very graceful effect can be obtained by placing the lower horizontal struts of the overhead bracing in a cylindrical surface similar to that which contains the panel points of the top chords, but, of course, with different curvature.

In respect to the decoration of each span of a bridge, it may be stated that a little ornamentation is generally much better than a great deal, and that this little should be appropriate and in keeping with the general character of the structure. A prodigal use of cheap cast-iron trimmings at a portal of a steel bridge is not in good taste, but it is perfectly proper to decorate the intersections of the members of the portal bracing by plates or rosettes, to surmount the upper horizontal portal strut by an æsthetically designed parapet, to use ornamental corner brackets beneath the lower portal strut, to employ fancy name-plates symmetrically arranged, and to place ornamental figures of proper size and design at the

hips, pedestals, or middle of inclined end posts. It is also permissible to ornament the intermediate transverse vertical bracing to a slight degree by rosettes and knee-braces, but such decoration should be applied sparingly. Again, in large bridges it is proper to be somewhat extravagant in the use of metal at the portal for the sake of appearance, especially as such metal, if it does not add to the strength of the bridge, certainly increases its rigidity.

The ornamentation of viaducts and elevated railways is something which has never received in America any attention worth mentioning, as is proved by the inherent ugliness of nearly all the elevated roads of our great cities, and the painful plainness of our railway trestles throughout the country. It is principally this neglect of æsthetics in design which has created such bitter opposition on the part of the property owners to the building of elevated roads in the heart of the city of Chicago.

Electric lights and gas-fixtures of artistic pattern can be made great aids in securing a pleasing effect in designs for bridges and viaducts; and at night a well-studied distribution of incandescent lights can be made to produce a brilliant appearance at the portals of any large and important city bridge.

Ornamental handrails are also of great service in decorating trestles and bridges. While these handrails must appear as subordinate to the main body of the structure they can be emphasized by paneling or open work. The posts separating the panels should be subordinate to the end posts. In small spans, the handrail should be of the open type in order not to make the span appear too massive and top heavy. For large spans a solid handrail is desirable in order to give more body to the profile of the bridge. A handrail should not terminate abruptly without some apparent cause. A curving or flaring of the handrails at the approaches of the bridge adds to the æsthetic effect. If this cannot be accomplished then some ornamental post of dignified size, suitably decorated and surmounted by an artistic lamp post, will be found very effective.

Architectural effect in bridge building seldom derives much aid from paint, for the reason that it is generally best, on account of both convenience and good taste, to use but one color in painting a bridge. A proper choice of color, however, is a material advantage; and it is correct to vary the color in certain accessory portions of the structure, such as machinery-houses, the lettering on name-plates, etc. Some engineers have advocated painting the tension and the compression members of different colors, but this would get one into difficulties in spans where certain strictly tension-members are made stiff. Ornamental figures should be painted of the same color as the rest of the bridge. In general, it may be stated that for ordinary conditions of landscape the heavier the structure the lighter should be the color of the paint used, for the reason that if a bridge has an appearance inclining toward clumsiness this objectionable effect can be lessened by reducing the prominence

of its members; while, on the other hand, a bridge which is of such an extremely light and airy design as to produce an appearance of weakness can be made to look stronger by adopting a paint of dark color, and thus bringing its members into greater relief in respect to surrounding objects. With very dark backgrounds, however, it will often be advisable to use a light-colored paint even for slight structures, so as to give the bridge a definite outline.

In regard to the ornamentation of bridges by the adoption of elaborately artistic approaches, but little has yet been done in America, the reason being that any money so expended has evidently no utilitarian purpose, and consequently to the eye of the solely practical man appears to be entirely wasted. In Europe it is customary to ornament large and important bridges in this way; and the time is coming when it will be the practice in America also.

Some twenty-one years ago the author had occasion to study quite thoroughly this question of the ornamentation of large bridges by employing elaborate but strictly unnecessary approach constructions. The occasion was that of a world-wide competition for plans of two bridges to cross the Danube River at Buda-Pesth, Hungary, into which competition he was unwise enough to enter. His plans were thrown out, notwithstanding the fact that they were probably the only ones that came within the set limits of costs of the structures or even at all near the said limits, on the plea that he had used higher unit stresses than those adopted in the specifications for the competition. Those unit stresses were fixed for spans of three or four hundred feet; and, as can be seen from Figs. 52*n* and 52*o*, the author's spans were three times as long, crossing the entire river from bank to bank in each case by a single span. As at that time the impact method of computing live-load stresses had not come into vogue, it was customary in America to increase slightly the intensities for working stresses for long-span bridges, and the author very properly followed that custom. The prize was awarded to a European competitor, who, by the way, had violated one of the fundamental requirements of the conditions by putting in estimates of cost nearly double those allowed. The reason for reproducing herein these layouts, which now properly pertain to ancient history, is to show the author's ideas as to what special gateways or entrances to large bridges should be like, as well as to indicate the fact that over two decades ago he had designed simple spans far longer than any that have yet been built or even seriously contemplated. These two designs, which are for spans of one thousand and forty and eleven hundred feet, respectively, were worked out in detail, not only stress sheets and details for truss connections, pedestals, floor system, lateral system, etc., being submitted, but also detailed plans for the false work and traveller, because the erection conditions were peculiar, the obstruction to navagation of the middle portion of the river being prohibited at all times.

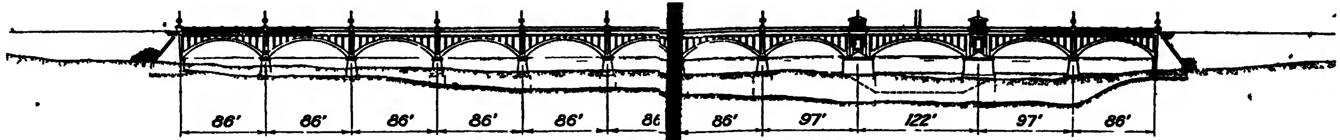


FIG. 52m. Proposed Thurlow Street Bridge over False Creek at Vancouver, B. C.

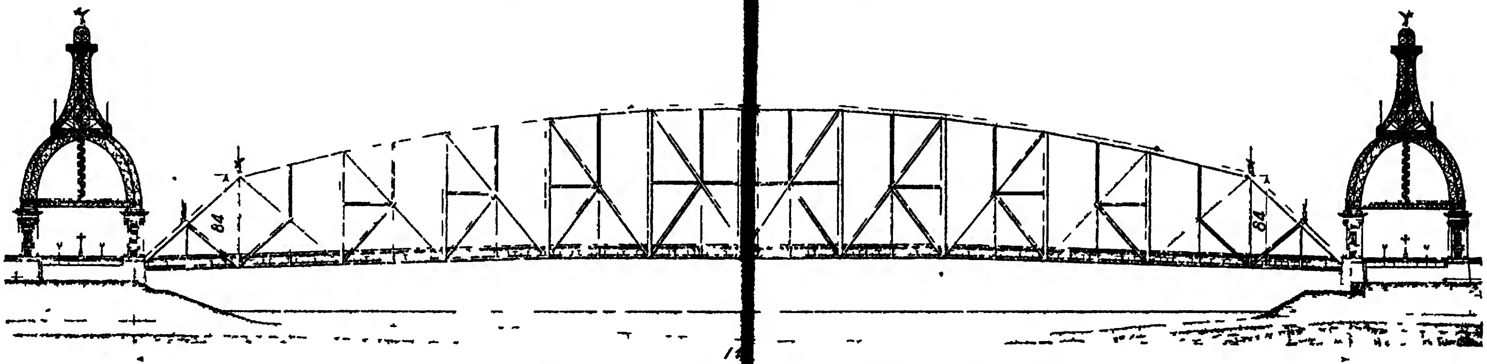


FIG. 52n. Proposed Bridge over the Danube River at Buda Pesth, Hungary, 1,040 Foot Span.

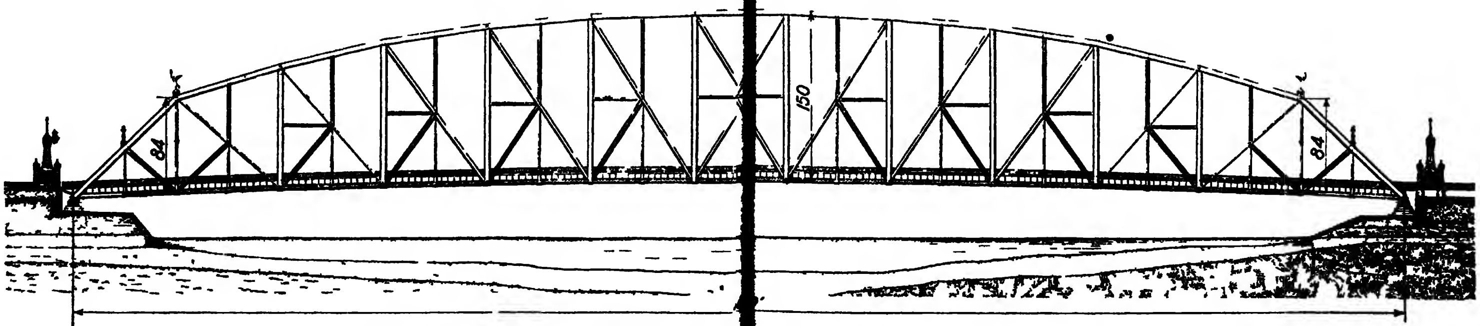


FIG. 52o. Proposed Bridge over the Danube River at Buda Pesth, Hungary, 1,100-Foot Span.

The shorter of the two spans, on account of its location, was required to be more elaborately ornamented than the other, hence in the former a steel construction having the effect of a dome surmounted with a tower was planned, while for the longer span a little castle at each of the four corners was deemed by the author to be sufficient. Much gray matter and, what was worse in those days, much good, solid cash were wasted on these plans and estimates, all going to prove the correctness of a statement made previously herein to the effect that it does not pay an engineer to compete on bridge plans without compensation, and unless the judges in the competition be truly bridge experts.

A proper proportioning of piers and abutments has a great deal to do with the obtaining of an artistically designed bridge; but, unfortunately, in these, even more than in the superstructure, the almighty dollar is generally the ruling influence in the design. In many bridges the piers do not seem to be massive enough for the spans; and, as is shown in Chapter XLIII, too often they are not sufficiently large to meet certain important engineering requirements, which are, as a rule, ignored by the average designer, and occasionally even by some who consider themselves bridge experts. In the author's opinion, if piers and abutments be adequately designed from an engineering point of view, they will not fall far short of the ideal of artistic excellence.

Believing that it will aid the reader in arriving at a better basis for his judgment to have pointed out the specific items or features of existing bridges worthy of commendation as well as those open to criticism, the author will avail himself of the excellent illustrations in Tyrrell's book on "Artistic Design of Bridges," to make further brief comment on bridges other than those previously mentioned. To avoid duplication of illustrations the reader is referred to that book.

Illustration No. 19 is that of an arch in Belle Isle Park, Detroit, Mich. The general effect is pleasing, but the solid handrail gives the structure a more massive appearance than it should have, considering the size of the opening. It is believed that an open-work handrail would have relieved this undue prominence of what should be a subordinate portion of the construction.

Illustration No. 20 is that of the proposed Hudson Memorial Bridge. While the ground profile prevented perfect symmetry, the general outlines of the structure are satisfactory.

Illustration No. 61 shows the outline of the Sukkur Bridge over the Indus River, India. It is totally lacking in every element of artistic design. The hard rigid profile, the derrick-like appearance of the cantilever arms, and the insignificance of the suspended span all offend the eye. Contrast this with the outline of the Beaver Bridge, No. 62, which even with its unsymmetrical layout caused by the end span has far more pleasing outlines. These two structures are also shown in Figs. 25*m* and 25*p* of this treatise.

Illustration No. 64 shows an effective steel-arch design and a good adjustment of floor elevation.

Illustration No. 65 is that of the Niagara Railroad arch span, which, considered by itself, is quite effective; but the sudden change from the arch to the shallow approach spans, without an intervening mass of masonry, is not pleasing to the eye. A semi-arch termination would have been more effective.

Illustration No. 71 shows capriciousness and lacks in beauty of outline.

Illustration No. 163 shows the effect of too short approach walls. The appearance of this structure would have been much enhanced if these walls had been lengthened and curved outwardly.

Illustration No. 164 presents another case of too short approach walls and also failure to merge with the landscape. Contrast these last two illustrations with that of No. 165.

Illustration No. 167 is that of the Forest Hills entrance to Franklin Park, Boston, Mass. Lack of symmetry is emphasized by the masonry portal at the high end.

Illustration No. 168 shows the effect of small spans and too many piers. The importance of the latter is minimized by the expanse of spandrel walls and solid handrail, which gives a top-heavy appearance to the structure. A better effect would have been secured by reducing the number of spans, lowering the springing line, and increasing the size of the piers.

Illustration No. 170 shows the effect of too long a span, leaving the arch ring to appear as if springing from the ground slope instead of the abutments. This obscuring of the skew-backs hides their function and leaves the eye unsatisfied.

Illustration No. 175 is of the bridge at Hyde Park, N. Y., on Hudson. In general outline this is a very satisfactory structure. However, the arch ring is merged into the spandrel walls and its function is obscured.

Illustration No. 183 presents an example of intrusion in the landscape. The abutments project out into the stream, producing ugly breaks in the shore lines. The suspension cables are not sufficiently defined, giving on this account an appearance of weakness.

Illustration No. 199 is that of the Rocky River Bridge at Cleveland, Ohio. The pleasing effect of this structure is marred by the heavy pilasters at the shore piers; for they have no apparent object other than supporting small balconies, or bartizans, at the floor level. These pilasters obscure the piers proper. The belt course at the springing line should have been carried entirely around the pier, and above this belt course the pilaster with diminished section should have extended to the balcony. Compare this pier with that of the Washington Bridge over the Harlem River, illustrated in "Modern Framed Structures." In the latter the skew-backs are well defined, the portion of pier below them is massive (as it should be since it takes up the thrusts of the arches), and the

portion above is subordinated by the smaller section, thereby bringing out its relative importance.

Illustration No. 205 is that of a highway bridge of reinforced concrete. This material is marked off to represent cut-stone masonry, which is in bad taste because it is deceptive; while the handrails or parapets are of rough rubble composed of boulders, giving the effect of strength and massiveness in the wrong place, in other words, overemphasizing the handrail.

Illustration No. 231 is that of the Kornhaus Bridge over the Aar at Berne, Switzerland. The main arch has a span of 384 feet and is terminated by handsome masonry piers, from which the smaller arches of the approach spans spring. Contrast the effect of this with that of the Niagara arch, shown in Illustration No. 65.

A critical study and comparison of these numerous illustrations in connection with the principles previously formulated in this chapter will assist the reader in cultivating his artistic perceptions and in the attainment of æsthetic results in his designing.

In concluding this chapter the author would advise his readers to read the whole of Tyrrell's book on "Artistic Design of Bridges," to consult the series of illustrations of European bridges in Vols. 43, 44, and 45 of the *Engineering Record*, and to study carefully Chapter XXVI on "The Æsthetic Design of Bridges," by David A. Molitor, Esq., C.E., in the "Theory and Practice of Modern Framed Structures." Although most of Mr. Molitor's illustrations are necessarily drawn from European structures, there are many features thereof which it would be well for American bridge-designers to adopt; notwithstanding the facts that European practice and American practice in bridge-building are fundamentally and essentially different, and that American engineers have little or nothing to learn from their brethren across the seas concerning the science of bridge design. From an artistic point of view, however, it must be confessed that the average American bridge is inferior to the average European structure; hence while it is advisable that American bridge-designers study carefully European practice in respect to æsthetics, they should be cautious to avoid thoughtless imitation; because decorative features which are appropriate to the heavy, massive, and costly bridges of Europe would be out of place when engrafted on some of the light, airy, and economic structures that may still be considered as characteristic of American bridge engineering, although the tendency nowadays in this country is toward heavier construction.

CHAPTER LIII

TRUE ECONOMY IN DESIGN

THE great majority of bridge designers believe that the most economic structure is the one for which the first cost is a minimum; and from the contractor's prejudiced point of view this is correct, because his interest generally lies in securing the contract for the work regardless of all other considerations than his own profits; but from the purchaser's point of view that structure is the most economic which will do the work required of it for as long a time as necessary with the least possible expenditure for operation, maintenance, and repairs, all these *desiderata* being obtained with the smallest practicable initial cost of construction.

In making an economic comparison of two or more designs for any proposed structure there are two methods of procedure, either of which is correct and satisfactory. The first is to find for each case what sum of money at the governing rate of interest will produce an income just sufficient to defray the average annual cost of operation, maintenance, repairs, and all other regular necessary expenditures, and add this amount to the total initial cost of the structure. The sum will be the "equivalent total first cost"; and if the designs be all satisfactory and the proposed structures of practically equal life, that structure for which the equivalent total first cost is the least is the most economic. The other method is to assume several future dates, preferably those at which certain large expenditures would probably have to be made for renewals or repairs of perishable portions, and compute the grand total cost to each date for each proposed structure under the assumption that it is then put into perfect condition, and allowing standard compound interest not only on the first cost but also on all annual expenditures. A comparison of these grand total costs at the several dates adopted will indicate clearly which is the most economic structure. A good example in the application of economics to bridges is given in Chapter LXX.

Treatise after treatise has been written upon the subject of economy in superstructure design, but unfortunately the result is simply a waste of good mental energy; for the writers thereof invariably attack the problem by means of complicated mathematical investigations, not recognizing the fact that the questions they endeavor to solve are altogether too intricate to be undertaken by mathematics. The object of each investigation appears to have been to establish an equation for the economic depth of truss, or that depth which corresponds to the minimum amount of metal required for the said truss; and, to start the investi-

gation, it seems to have been customary to make certain assumptions which are not even approximately correct. For instance, the principal assumption of several treatises in French and English is that the sectional area and the weight of each member of a truss are directly proportional to its greatest stress; or, in other words, that in proportioning all members of trusses a constant intensity of working stress is to be used, while in reality for modern steel bridges the intensities often vary considerably in the same specifications. Again, no distinction is made between tension and compression members, and no account is taken of the greatly varying amounts of their percentages of weights of details.

There is, however, one mathematical investigation concerning economic truss depths which is approximately correct, and which is based on assumptions that are very nearly true; but it holds good only for trusses with parallel chords. It is this:

Let A = weight of the chords,
B = weight of the web,
C = weight of the truss,
and D = depth of the truss.

Then
$$C = A + B. \qquad \text{[Eq. 1]}$$

But the weight of the chords varies inversely as the depth, or $A = \frac{a}{D}$, and the weight of the web varies directly as the depth, or $B = bD$, where a and b are constants; and, therefore, $C = \frac{a}{D} + b\,D$.

If C is to be made a minimum, we shall have, by differentiation,

$$\frac{d\,C}{d\,D} = -\frac{a}{D^2} + b = 0, \qquad \text{[Eq. 2]}$$

or
$$-\frac{A}{D} + \frac{B}{D} = 0, \text{ or } A = B. \qquad \text{[Eq. 3]}$$

As the second differential coefficient, after substitution according to the usual method for maxima and minima, comes out positive, the result obtained corresponds to a minimum. From this it is evident that, for trusses with parallel chords, the greatest economy of material will prevail when the weight of the chords is equal to the weight of the web. The author has verified this conclusion by checking the weights of chords and webs in a number of finished designs, finding it to be absolutely reliable. However, it is not of much practical value, because the economic depths of trusses with parallel chords are pretty well known; and, again, when spans are in excess of 175 or 200 feet, the chords of through-bridges are seldom made parallel. Moreover, the best depth to use is not often the one which gives the least weight of metal in the trusses.

It has been found by experience that, for trusses with polygonal top

chords, the economic depths, as far as weight of metal is concerned, are generally much greater than certain important conditions will permit to be used. For instance, especially in single-track, pin-connected bridges, after a certain truss depth is exceeded, the overturning effect of the wind-pressure is so great as to reduce the dead-load tension on the windward bottom chord to such an extent that the compression from the wind load carried by the lower lateral system causes reversion of stress, and such reversion eye-bars are not adapted to withstand. A very deep truss requires an expensive traveller, and decreasing the theoretically economic depth increases the weight but slightly; hence it is really economical to reduce the depth of both truss and traveller. Again, the total cost of a structure does not vary directly as the total weight of metal, for the reason that an increase in the sectional area of a piece adds nothing to the cost of its manufacture, and but little to the cost of erection; consequently it is only for raw material and freight that the expense is really augmented. Hence it is generally best to use truss depths considerably less than those which would require the minimum amount of metal. For parallel chords, the theoretically economic truss depths vary from one-fifth of the span for spans of 100 feet to about one-sixth of the span for spans of 200 feet; but for modern single-track-railway through-bridges the least allowable truss depth is about 30 feet, unless suspended floor-beams be used, a detail which very properly has gone out of fashion.

In two five-hundred-foot spans of a combined railway and highway bridge the author employed a truss depth of seventy-two feet; but this was determined by the reversal of stress in bottom chords through wind-pressure. A greater depth, if permissible, would have caused a saving in total weight of metal. In another of his designs for a five-hundred-and-sixty-foot span a truss depth of ninety feet was adopted, but in this case the live load was very great, varying from ten thousand pounds per lineal foot for short spans to eight thousand pounds per lineal foot for long ones; and the bridge is twenty per cent wider than in the case of the two five-hundred-foot spans just mentioned. The greater the live load and the wider the bridge, the greater generally can the truss depth be made advantageously.

The little mathematical investigation given in this chapter can be applied with fair accuracy to plate-girder bridges and to the floor systems of truss-bridges. If, for ordinary cases, in designing plate girders, one will adopt such a depth as will make the total weight of the web with its splice-plates and stiffening angles about equal to the weight of the flanges, he will obtain an economically designed girder, and a deep and stiff one. For long spans, however, this arrangement would make the girders so deep as to become clumsy and expensive to handle; consequently, when a span exceeds about forty feet, the amount of metal in the flanges should be a little greater than that in the web; and the more the span exceeds forty feet the greater should be the relative amount of metal in the flanges.

The true economic investigation for plate-girders is as follows, when the web is assumed to resist its share of the bending moment:

Let M = bending moment at mid-span,

h = depth of web,

t = thickness of web,

S = intensity of working stress for tension,

l = length of span,

and c = ratio of weight of details of web (*i. e.*, end stiffeners, intermediate stiffeners, splice plates, and fillers) to weight of the web plate itself.

The sum of the two flange areas at mid-span, including an allowance of fifteen per cent for rivet holes, will be given by the equation,

$$F = 1.15\left(\frac{2M}{hS} - \tfrac{1}{4}ht\right); \qquad \text{[Eq. 4]}$$

and the total weight of metal in the flanges, taking into account the fact that the cover plates do not run the full length of the girder, will be given approximately by the equation,

$$W_f = 3.4 \times 1.15\left(\frac{2M}{hS} - \tfrac{1}{4}ht\right) \times 0.8\,l,$$

$$= 3.4\,l\left(\frac{1.84\,M}{h\,S} - 0.23\,h\,t\right). \qquad \text{[Eq. 5]}$$

The weight of the web and its details will be

$$W_w = 3.4\,l\,(h\,t + c\,h\,t). \qquad \text{[Eq. 6]}$$

Therefore the total weight of girder will be

$$W_g = 3.4\,l\left(\frac{1.84\,M}{h\,S} - 0.23\,h\,t + h\,t + c\,h\,t\right),$$

$$= 3.4\,l\left(\frac{1.84\,M}{h\,S} + 0.77\,h\,t + c\,h\,t\right). \qquad \text{[Eq. 7]}$$

Differentiating with respect to h and placing the differential coefficient equal to zero gives

$$\frac{d\,W_g}{d\,h} = 3.4\,l\left(-\frac{1.84\,M}{h^2\,S} + 0.77\,t + c\,t\right) = 0. \qquad \text{[Eq. 8]}$$

Hence

$$\frac{1.84\,M}{h\,S} = 0.77\,h\,t + c\,h\,t; \qquad \text{[Eq. 9]}$$

from which we find

$$\frac{1.84\,M}{h\,S} - 0.23\,h\,t = 0.54\,h\,t + c\,h\,t, \qquad \text{[Eq. 10]}$$

and $$3.4\,l\left(\frac{1.84\,M}{h\,S} - 0.23\,h\,t\right) = 3.4\,l\,(0.54\,h\,t + c\,h\,t). \quad \text{[Eq. 11]}$$

But the value of c is generally about 0.3. Substituting this gives

$$3.4\,l\left(\frac{1.84\,M}{h\,S} - 0.23\,h\,t\right) = 3.4\,l\,(0.84\,h\,t). \quad \text{[Eq. 12]}$$

But the first member of this equation represents the weight of the flanges for the most economic condition, and the second member is eighty-four per cent of the total weight of the web plate without its details.

Dividing both sides of the last equation by 0.8 and cancelling the $3.4l$ gives

$$\left(\frac{2.3\,M}{h\,S} - 0.29\,h\,t\right) = 1.05\,h\,t, \quad \text{[Eq. 13]}$$

or $$1.15\left(\frac{2\,M}{h\,S} - 0.25\,h\,t\right) = 1.05\,h\,t. \quad \text{[Eq. 14]}$$

Evidently the first member of this equation represents the gross area of the flanges and the second member differs only a little from the gross area of the web and may without any great error be called such. Hence it may be stated that the theoretical maximum of economy exists when the gross areas of flanges and of web at mid-span are equal—a condition readily remembered. If the depth of the web be selected on this basis, rather than by the older criterion which makes the total weight of flanges equal to the total weight of the web with all its details, it will be found to give a greater web depth. This increased depth is likely to augment the cost from one or more of the following practical considerations, which the formula cannot take into account.

A. An additional splice or two in the web, or else a slightly increased pound price for the large plates.

B. Larger outstanding legs for all stiffening angles.

C. Reduction in the number of cover plates.

D. Narrowing of flange angles and necessitating thereby either an additional bracing frame or an increase in sectional area of the compression flange, in order to compensate for the greater ratio of unsupported length to width.

E. Possible thickening of web because of its greater depth.

F. Possible encroachment on under-clearance in deck spans, or raising of grade to avoid the same.

G. Possible difficulty in fabrication or shipment in case of long or heavy girders because of excessive depth.

Any one of these changes would be likely so to upset the economics of the case as to cause a material decrease in the theoretical depth found by the preceding investigation. One will not often make an error in economy by following the old established rule given in *De Pontibus* and reproduced herein previously to the effect that the best practicable arrangement is generally to make the weight of the flanges equal to the

weight of the web and its details; and there are occasionally cases where a saving of metal can be effected by making the web depth even smaller than that given by this old criterion, when by so doing a web splice may be avoided or smaller stiffening angles may be adopted. It should be borne in mind that there is quite a range in web depths over which the theoretic minimum weight is about constant, unless the thickness of the shallower web must be increased on account of the shear; hence one may often vary the dimensions of a plate-girder materially without affecting greatly the matter of economics. In Fig. 21*e* is given a diagram of economic depths of plate-girders with riveted end connections.

Concerning economic panel lengths, it is safe to make the following statement:—Within the limit set by good judgment and one's inherent sense of fitness, the longer the panel the greater the economy of material in the superstructure. Of course, when one goes to such an extent as to use a thirty-foot panel in an ordinary single-track-railway bridge he exceeds the limits referred to, because the lateral diagonals become too long, and their inclination to the chords becomes too flat for rigidity. Again, an extremely long panel might sometimes cause the truss diagonals to have an unsightly appearance because of their small inclination to the horizontal.

There is another mathematical investigation which is of practical value. It relates to the economic lengths of spans, and was first demonstrated in print by the author some twenty-five years ago in "Indian Engineering," although the principle was announced three years before then in the first edition of his "General Specifications for Highway Bridges of Iron and Steel." Strange to say, many engineers failed to see that there is any difference between this principle and an old practice of over fifty years' standing. The principle is that "for any crossing the greatest economy will be attained when the cost per lineal foot of the substructure is equal to the cost per lineal foot of the trusses and lateral systems." The old practice was to make for economy the cost of a pier equal to the cost of the span that it supports, or, more properly, equal to one-half of the cost of the two spans that it helps to support. Is not the difference between these two methods perfectly plain? In one the cost of the pier is made equal to the cost of the trusses and laterals, and in the other it is made equal to the cost of the trusses, laterals, and floor system. When one considers that the cost of the floor system is sometimes almost as great as one-half of the total cost of the superstructure, he will recognize how faulty the old method was. The following is the demonstration of the principle, simplified to the greatest practicable extent.

Let us assume a crossing of indefinite length, for which the depth of bed-rock is constant, and let

S = cost of the substructure per lineal foot of span,

T = cost per lineal foot of the trusses and laterals,

F = cost per lineal foot of the floor system,
B = cost per lineal foot of the entire bridge,
and L = length of span.
Then

$$B = S + T + F. \qquad \text{[Eq. 15]}$$

Now if we assume that slight changes in length of span will not affect materially the sizes of the piers, the cost per foot of the substructure will vary inversely as the span length,

or

$$S = \frac{s}{L}. \qquad \text{[Eq. 16]}$$

Again, the cost per foot of the trusses and laterals, for slight changes in length of span, may be assumed to vary nearly directly as the span length; hence we may write the equation

$$T = t\,L. \qquad \text{[Eq. 17]}$$

The cost per foot of the floor system is practically independent of the span length, being a function of the panel length, which does not change materially with the span.

We now have the equation

$$B = \frac{s}{L} + t\,L + F. \qquad \text{[Eq. 18]}$$

in which B is to be made a minimum.

Differentiating and substituting, we have (as F is a constant)

$$\frac{d\,B}{d\,L} = -\frac{S}{L} + \frac{T}{L} = 0, \text{ or } S = T. \qquad \text{[Eq. 19]}$$

A further differentiation shows that the result corresponds to a minimum.

In reality the truss weight per foot increases more rapidly than the span length. If r is the ratio of the span lengths, the truss weights per foot, for small changes in span lengths, will vary almost exactly according to the ratio $r' = \frac{1}{2}(r + r^2)$. On the other hand, the weight per foot for the lateral system does not increase quite as rapidly as the span, unless the perpendicular distance between central planes of trusses also increases. Unfortunately, though, the gain in truss weight over that given by the assumed theory of variation is generally greater than the corresponding loss for the weight of lateral system, consequently the combined weights per foot of trusses and laterals generally increase a trifle faster than the span length. This is partially offset by the fact that the pound price of metal erected and painted will reduce a trifle as the weight per foot increases. Again, there is often a small error in the assumption that the cost of the piers varies inversely as the span length, because the size of each pier may have to be increased a little to accommodate the heavier spans; and this error is considerable for piers

which rest on piles. If the perpendicular distance between central planes of trusses is increased because of the greater span length, the cost of each pier will be increased because of its greater length; but this will occur only occasionally. Ignoring the latter contingency, the two errors indicated, notwithstanding the fact that their effects are additive, are so small as not to affect materially the correctness of the results of this investigation concerning economic span lengths.

This demonstration proves that, in any layout of spans, with the conditions assumed, the greatest economy will be attained when the cost of the substructure per lineal foot of bridge is equal to the cost per lineal foot of the trusses and lateral systems. Of course, no such condition as a bridge of indefinite extent ever exists, nor is the bed-rock often level over the whole crossing; nevertheless the principle can be applied to each pier and the two spans that it helps to support by making the cost of the pier equal to one-half of the total cost of the trusses and laterals of the said two spans. Since working out this demonstration more than twenty-eight years ago, the author has made a practice of checking the correctness of the principle thereby established, by comparing the cost of substructure and superstructure in the principal bridges which he has designed and built, with the result that he finds it to be invariably correct.

The principle will apply also to trestles and elevated roads; for in the latter, when there is no longitudinal bracing, if we make the cost of the stringers or longitudinal girders of one span equal to the cost of the bent at one end of same, including its pedestals, we shall obtain the most economic layout. In an ordinary railroad trestle consisting of alternating spans and towers, it will be necessary for greatest economy to have the cost of all the girders in two spans (one span being over the tower) plus the cost of the longitudinal bracing of one tower equal to the cost of the two bents of said tower, including their pedestals.

The economics of reinforced concrete bridges have not received much attention from technical writers; and they are rather difficult to determine, as the quantities involved are influenced quite largely by the individual tastes of the designer. The problem is also complicated by the facts that the unit costs of the various portions of a structure may be more or less different, and that the unit costs of different types of construction may be decidedly unlike. In general, it may be said that the unit costs are lower for those structures which have the simplest form work; and a reduction will also be effected by decreasing the area of form surface per cubic yard of concrete. For instance, in the case of a wall or slab the form cost per cubic yard will vary practically inversely as the thickness of the said wall or slab. Evidently, therefore, it is desirable to concentrate the concrete into a few large members, rather than to employ a great number of small ones.

It should be noted that reinforcing bars less than ¾″ in diameter

command higher pound prices than do the larger bars. The extras for these small bars may be found in *Engineering News* the first of each month.

Taking up first girder bridges carried on columns, the following points must be considered:

First.—The panel length, when cross-girders are employed.
Second.—The number and spacing of the longitudinal girders.
Third.—The number of columns per bent.
Fourth.—The span length.
Fifth.—The use of reinforced concrete piles to carry the footings.

The panel length adopted is usually not of great importance from the standpoint of economy. Lengths of from eight to ten feet are generally employed; but a considerable variation from these values will cause little change in the combined cost of the slabs and cross-girders. A reduction in concrete quantities can frequently be effected by using long panels, and by carrying the slabs on short stringers supported by the floor-beams; but the extra form work required will generally overbalance this saving in volume.

The number and spacing of the longitudinal girders will depend upon the width and the height of the structure, the span length, and the load to be carried. For a high structure in which the economic span length is fairly long, it will nearly always be found best to employ two lines of girders, the spacing thereof being equal to about five-eighths of the total width of the structure; but for bridges much over sixty (60) feet wide the use of three or even four lines may be preferable. The slab in such structures is carried on cross-girders and cantilever-beams. For a low bridge in which the economic span length is short, it will generally be the cheapest to omit the cross-girders, except at the bents, and to employ several lines of longitudinal girders. The wider the structure, the more likely will this arrangement prove to be economical; and very heavy loads also favor its adoption. For a structure in which the span length is from one-half to two-thirds of the width, it will usually make little difference which of the two types is adopted, unless the height is rather large; and even in extreme cases the variation between the two is not likely to exceed ten per cent. Ordinarily, it will be found more desirable to use two lines of girders, with cross-girders and cantilevers about eight or ten feet centres.

The proper number of columns per bent depends on the number of longitudinal girders When there are only two lines, two columns will, of course, be employed. When there are several lines of girders, there should generally be one column per girder in low structures, and two columns per bent in higher ones. In this latter case a heavy cross-girder will be required at each bent to carry the longitudinal girders.

The economic span length is affected by the height and the load, being

larger for greater heights and smaller for heavier loads. An approximate value thereof is given by the formula

$$l = h\left(0.3 + \frac{2000}{w + 1000}\right), \qquad \text{[Eq. 20]}$$

in which l = economic span length, centre to centre of supports,
w = load per lineal foot of girder (excluding its own weight),
and h = fixed height of structure.

The quantity h represents in any given case the height which is fixed, such as the height from grade to top of footing, height from grade to bottom of footing, height from underside of girder to top of footing, or height from underside of girder to bottom of footing, as the case may be. There is always a considerable range of lengths for which the quantities remain nearly constant. The formula gives values a trifle greater than those for which the quantities are a minimum, since the use of heavier sections will reduce slightly the unit costs of the concrete.

Reinforced concrete piles should be used under footings when a suitable foundation is to be found only at a considerable depth, or when a very large footing area would be required in order to reduce the pressures to a proper amount. A comparison must be made for each case as it arises, allowing properly for the cost of the column shaft, the footing, the piles, and the excavation. This latter item must not be overlooked.

The curves of Figs. 56t to 56y, inclusive, will be found of great value in studying the questions of economy of girder bridges, as most of the points involved can be settled directly thereby.

In arches the problem is much more complicated than in girder spans. The factors that affect the economic lengths are the cost of the arch ribs and that of the piers and abutments, the dividing lines between them being the verticals through the springing points. For any fixed span length the greater the rise, up to a limit of nearly one-half of the opening, the smaller will be the costs of both the arch and the piers or abutments which sustain it; but in most cases the distance from grade to ground is too small to permit the adoption of such a large rise; hence the problem generally resolves itself into a determination of the question, "How long can the span be made economically for a certain limit of rise?" This will be influenced by several important considerations, among which may be mentioned the following:

A. The live load used.

B. The amount of earth fill, if any, over the arches.

C. The depth of the foundations for the piers and abutments below the springing points.

D. The cost per cubic yard for putting the bases of piers and abutments down to a satisfactory foundation.

E. The necessity for a heavy or substantial appearance of the piers and abutments.

F. The height to which the large pier shafts must be carried.

G. The condition of the arch barrel—whether solid or ribbed.

H. The necessity, or otherwise, of adopting certain span lengths to meet existing conditions.

Here are too many variables for a theoretically correct economic investigation, hence the surest and most satisfactory way to proceed is to make by judgment the best possible layout consistent with the conditions, then two others, one involving a span length a certain number of feet greater and the other a span length the same number of feet less, and figure the costs of arches and piers (or abutments) for all three cases. Instead, though, of increasing and decreasing the span by a certain number of feet it may be necessary to reduce and augment the number of spans by unity. After the costs of the arches and piers or abutments are found and properly combined, the cost of these two portions of the construction per lineal foot of span for each of the three layouts can be computed and compared. The one which gives a minimum will indicate approximately the best span length to adopt.

In some cases it will prove to be economic to make the middle span of the bridge a certain length and reduce gradually the lengths of the spans at each side. If the configuration of the crossing will permit of a symmetrical layout on this basis, the effect will prove to be pleasing to the eye and generally economic of first cost, especially if a constant ratio of rise to span be maintained; because, as far as cost of substructure is concerned, the overturning moments from live load on a single span only and from inequality of dead load thrusts are kept low, owing to the fact that the lighter thrusts in the smaller span act with a greater lever arm than do the heavier thrusts of the longer span, on account of higher location of the points of springing. In adopting this expedient, though, care has to be exercised to prevent the principles of æsthetics from being violated.

The curves of Figs. 56*z* to 56*cc* will be found very useful in determining the economic span lengths of arch bridges.

There are many minor economic questions that arise in the designing and construction of bridges, among which may be mentioned the economic greatest lengths of different types of spans; the character of approaches to bridges; column spacing in bents supporting cross-girders with cantilever brackets; the economic functions of swing spans, cantilever bridges, arches, and steel trestles; the height of concrete retaining walls at which it is economic to begin to use reinforcing; the relative economics in employing medium steel, soft steel, standard steel, and alloy steel for bridge superstructures; the effect of erection on the economic layout of spans; the comparative economics of rim-bearing and centre-bearing swing spans; economy in choice of metal sections; and economy in shopwork. These various economic questions will now be taken up in the order enumerated.

Comparing rolled I-beam and plate-girder deck spans for modern

heavy live loads, the weights of metal are about equal for spans of fifteen feet; but the former are cheaper per pound than the latter by about four-tenths (0.4) of a cent, consequently the costs per lineal foot erected are equal for a span of about twenty feet.

Comparing deck plate-girders and through, riveted truss-spans, for which there is usually a difference of about one-half cent per pound erected in favor of the former, the weights of metal per lineal foot are the same for spans of one hundred and fifteen (115) feet, which is about the extreme limit of length for plate-girder spans shipped in one piece; hence it may be concluded that for all practicable lengths, deck plate-girder spans are more economic than through, riveted truss-spans. Besides, the use of such deck spans effects a great economy in the substructure by reducing the length of each pier from six to ten feet, the longer the span, of course, the less the reduction.

Comparing half-through, plate-girder spans and through, riveted truss-spans, for which there is a difference of about two-tenths (0.2) of a cent per pound erected in favor of the former, the weights of metal per lineal foot are the same for spans of seventy (70) feet, but the costs per foot are about equal for spans of seventy-five (75) feet. However, as plate-girder spans are in many respects more satisfactory than short, through riveted spans, the dividing point is generally placed at about one hundred (100) feet.

Comparing Pratt and Petit truss-spans, for which there is no difference worth mentioning in the pound prices of the metal, the weights per foot (and therefore the costs) are alike for single-track spans of three hundred (300) feet, and for double-track spans of three hundred and fifty (350) feet; but both constructive and æsthetic reasons necessitate limiting the lengths of Pratt trusses to about three hundred and twenty-five (325) feet.

The economics of approaches to bridges will involve the question of whether it is best and cheapest to build earth embankments, timber trestles, or steel viaducts, and at what heights it would pay to change from one kind to the other. Figs. 53*a* and 53*b* give the costs per foot of single-track and double-track earth embankments at various prices per cubic yard for earthwork; Figs. 53*c* and 53*d* give the costs per lineal foot of single-track and double-track timber trestles for various prices per M feet B. M. of timber in place; and from Figs. 55*nn* to 55*zz*, inclusive, and Figs. 56*k* to 56*m*, inclusive, can be computed the cost per lineal foot of steel viaducts. In estimating the cost of embankment, that of the retaining walls, abutments and culverts must be included. The cost of reinforced and plain concrete retaining walls can be determined from Figs. 56*r* and 56*s*, and that of plain concrete abutments can be taken directly from Fig. 53*e*. It must not be overlooked in this comparison that the quantities in Figs. 53*c* and 53*d* include the timber deck, which is not the case in the other diagrams. This economic study will involve

the consideration of interest, maintenance, depreciation, and repairs, as indicated at the beginning of this chapter.

The economics of column spacing for bents when cantilever brackets are employed is an interesting little problem, but the final determination must be in accordance with good judgment as well as economy; for if the spacing be too small, rigidity is likely to be sacrificed. Upon certain assumptions of approximate correctness the mathematical solution of this problem is a possibility; but the equations involved would be so complicated that it is much better for any particular case to assume two or three spacings, compute the total weight of metal in the bent for each, and find the one which will give approximately the least weight of metal. If the columns are placed at the quarter points of the beam, the dead load bending moment at the middle will be approximately zero; and if the effect of stress reversion is ignored, the direct and reverse bending moments for the central portion of the beam will be equal, and this arrangement would be about the most economical possible. But if the reversion is considered, the sectional area of the middle portion of the beam must be greater than that of the outside portions, hence for economy its length should be somewhat less than one-half of the total, and the columns would then be spaced somewhat closer than when they are located at the quarter points. The fact that the brackets are usually lighter near the outer ends than at the inner ones would, for economy, tend to draw the columns together; but on the other hand this would increase the weight of the splices and connecting details. The proper column spacing to adopt will depend upon the length of the columns; for it is easily conceivable that the structure could be so high and so narrow that the quarter point spacing would be too close for proper resistance to wind pressure. Again, in such a case the wind load might be so great as to necessitate an increase in column section above that required to care for the live and dead load stresses only; and thus the effect of wind pressure would enter the economic study. It will be found in most cases that it is inadvisable to space the columns much less than one-half of the total length of the beam.

The economic functions of swing spans are somewhat difficult to formulate. The minimum perpendicular distance between central planes of trusses for first-class construction should be the same as for simple truss spans, viz., one-twentieth of the span length. It is evident, of course, that the narrower the bridge the less it will weigh and cost. The truss depths at ends of through swing bridges are generally determined by the clearance requirements; but in long spans it is sometimes advisable, for the sake of vertical stiffness and to avoid the raising of span-end from a load on the other arm, to make the said depths still greater. As a rule, this increase is not of an uneconomic nature. For long spans, or those exceeding, say, four hundred (400) feet, the truss depth at outer hips should be about one-fourteenth ($^1/_{14}$) or one-fifteenth ($^1/_{15}$) of the total

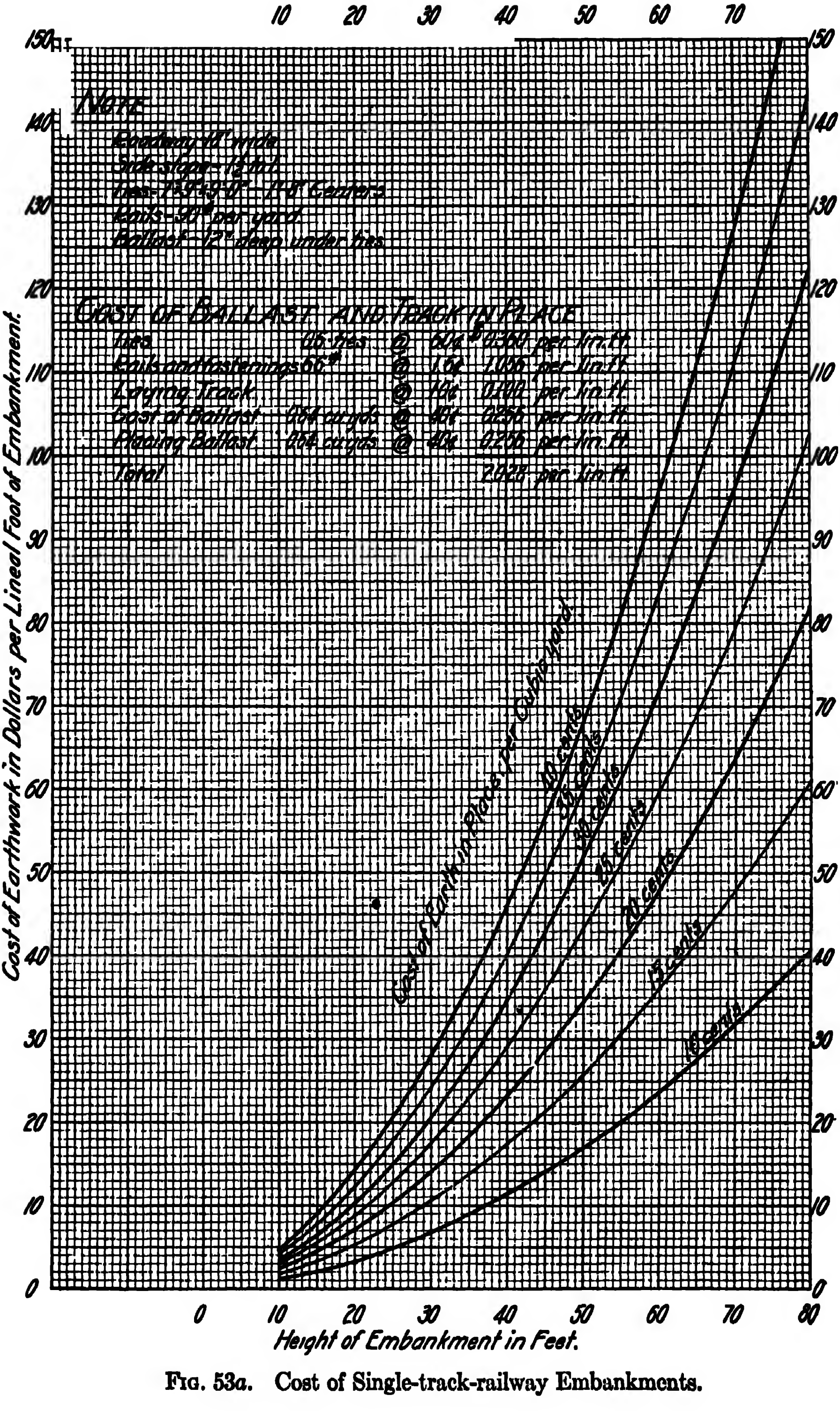


FIG. 53a. Cost of Single-track-railway Embankments.

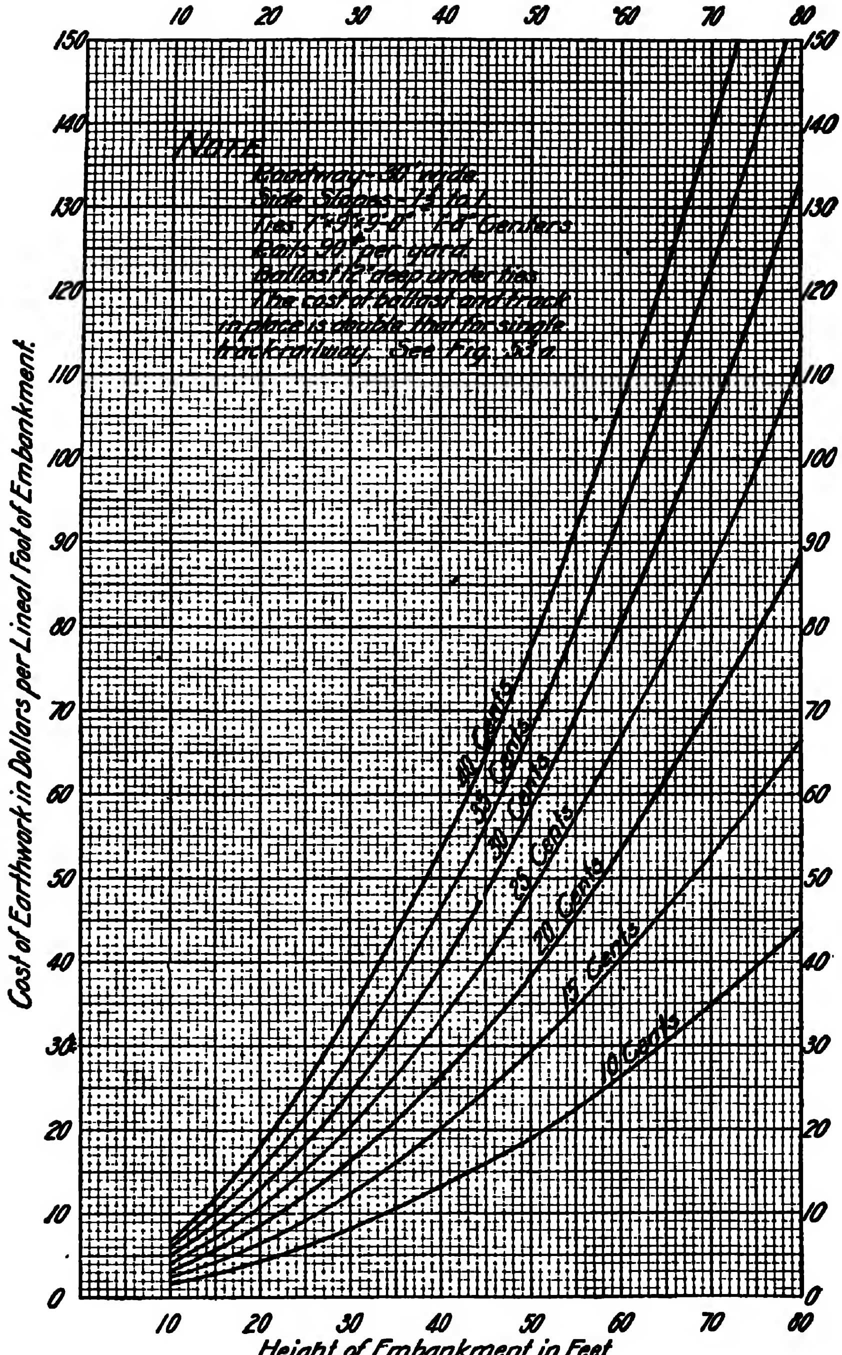
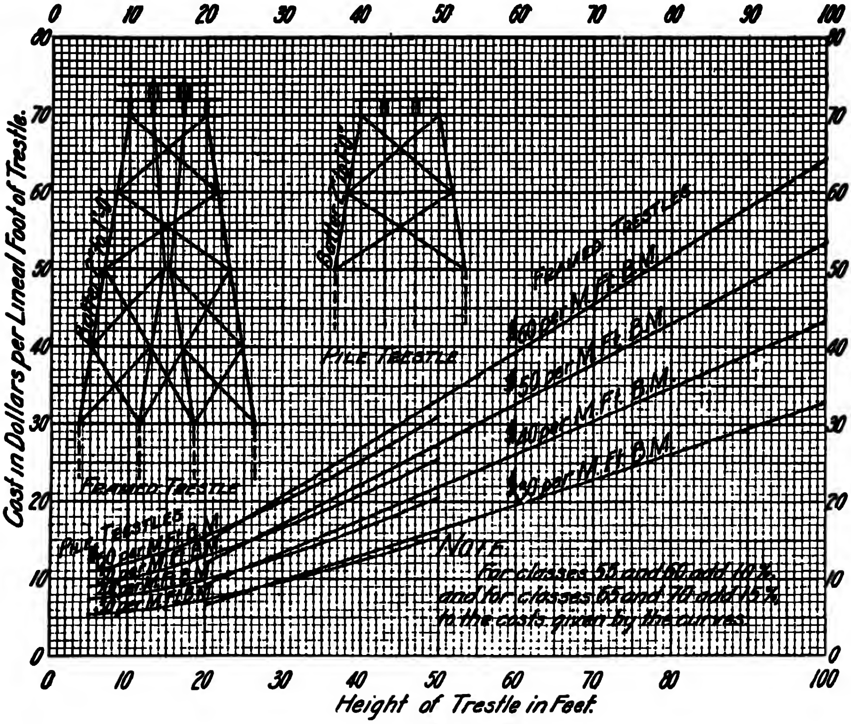


FIG. 53*b*. Cost of Double-track-railway Embankments.

span length. The truss depth at the inner hips should generally be from one-ninth ($\frac{1}{9}$) to one-tenth ($\frac{1}{10}$) of the total span length; and when towers are used their height should generally be from one-sixth ($\frac{1}{6}$) to one-seventh ($\frac{1}{7}$) of the span. Of course, the æsthetic features of the design



Cost includes trestle complete, but not track rails.

Panel lengths for pile trestles are 14′ 0″, and for framed trestles, 28′ 0″.

In pile trestles, piles are assumed to have a 10′ penetration, and to cost 35 cents per lineal foot.

In framed trestles, two 20′ piles, each costing 35 cents per lineal foot, are provided under each post.

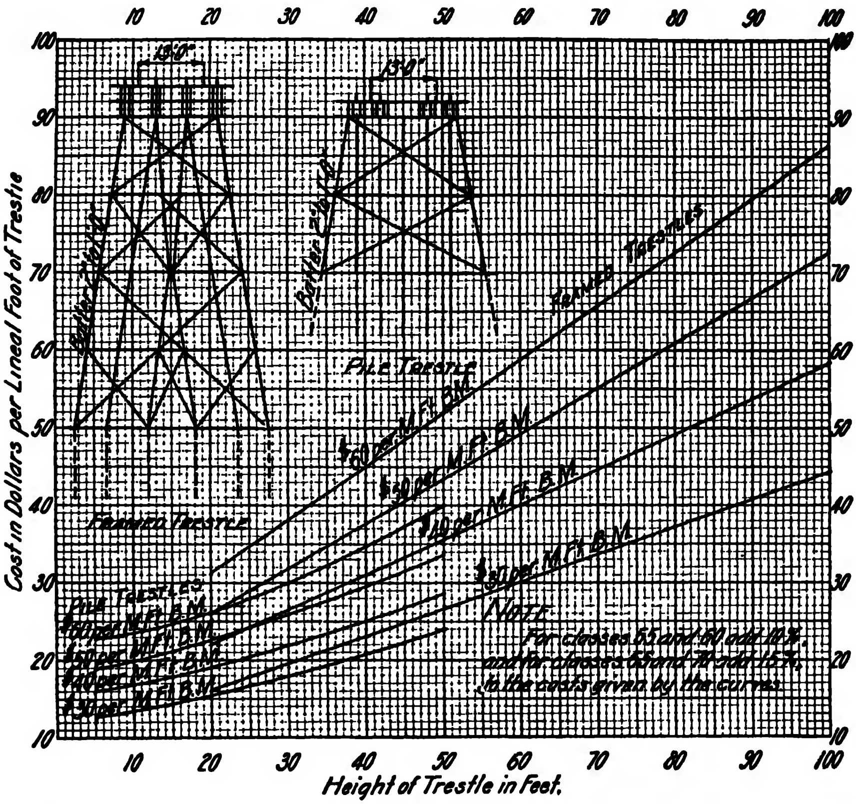
Fig. 53c. Cost of Single-track-railway, Wooden Trestles.

should govern greatly the determination of all these depths; and, fortunately, any moderate change in them does not affect materially their economics.

In swing spans it is evident that, as far as is consistent with safety, the diameter of the drum for economy should be made as small as possible, not only because this effects a saving of metal, but also because it reduces the diameter, and therefore the cost, of the pivot pier. For spans of moderate length and width there is generally a small economy in centre-bearing swing-spans over rim-bearing ones, especially as the former sometimes permit of smaller pivot piers, but the difference is often inconsiderable. There is a limit to the size of centre-bearing swing-spans due to the ob-

jectionable feature of concentrating great loads upon small areas and to the necessity in the case of very wide spans for excessively heavy cross-girders. The question of economics between the two styles of swings is one that has to be determined for each special case as it arises by preparing actual estimates and not by *a priori* reasoning.

As mentioned in Chapter XXV and previously in *De Pontibus*, the



Cost includes trestle complete, but not track rails.

Panel lengths for pile trestles are 14′ 0″, and for framed trestles, 28′ 0″.

In pile trestles, piles are assumed to have a 10′ penetration, and to cost 35 cents per lineal foot.

In framed trestles, two 20′ piles, each costing 35 cents per lineal foot, are provided under each post.

FIG. 53*d*. Cost of Double-track-railway, Wooden Trestles.

economics of cantilever bridges formed the subject of a special investigation for that treatise, the result of which was as follows:

First. The economic length of the suspended span is about three-eighths (3/8) of the length of the main opening, but a considerable increase or decrease of this proportion does not greatly change the total weight of the metal.

Second. The most economic length of anchor arms, where the total length between centres of anchorages is given, and when the main piers

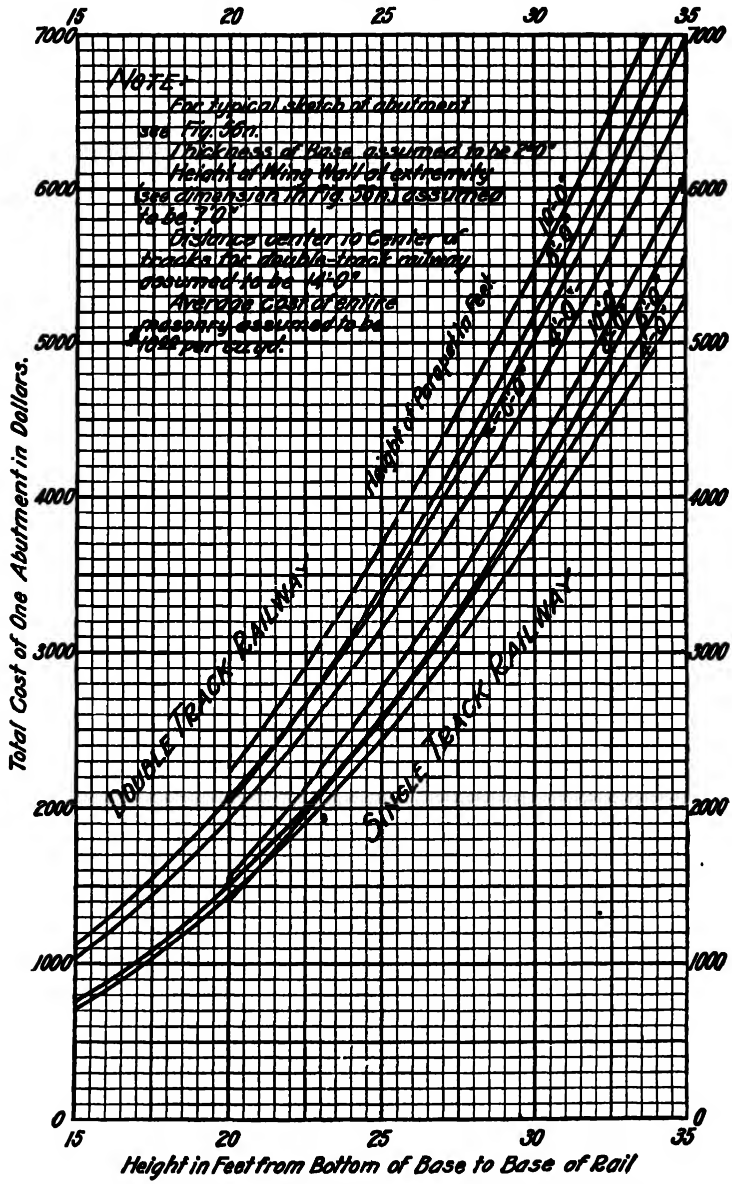


FIG. 53e. Cost of Plain-concrete Railway-abutments.

can be placed wherever desired, is one-fifth ($\frac{1}{5}$) of the said total length. By keeping the anchor arms short the top chords may be built of eyebars, provided that with the usual allowance for impact there is no reversion of chord stress; and this effects quite an economy of metal. But

it is conceivable that cases might arise where, from danger of washout of falsework, eye-bar top chords would be objectionable; hence this method of economizing must be used with caution.

Third. In respect to the economic length of anchor-span in a succession of cantilever spans, it may be stated that within reasonable limits the shorter such anchor-spans are the greater will be the economy involved; but generally navigation interests will prevent their being built as short as might be desired. If permissible, they may be made so short that, as in the case of anchor-arms, eye-bars may be used for the top chords, thus effecting a decided economy of metal, although shortening the anchor-span increases proportionately the stresses on the web members and the weights thereof.

The question of what is the economic limit of length of simple truss spans as compared with cantilevers is still a mooted one. Professors Merriman and Jacoby, on page 119 of Part IV of their excellent treatise on "Roofs and Bridges," state that the economic limit for simple spans was probably nearly reached in the building of the five hundred and eighty-six (586) foot span over the Great Miami River at Elizabethtown near Cincinnati; but the author has had occasion to compare simple truss spans of seven hundred (700) and eight hundred (800) feet with the corresponding cantilever structures and has found them more economic. This question is discussed at length on page 587, *et seq.*, and the reader is referred thereto. The continuity of cantilever spans in resisting wind loads lowers the requirement for minimum width from one-twentieth ($1/20$) to about one twenty-fifth ($1/25$) of the greatest span length, and hence, because of substructure considerations, gives an advantage to the cantilever type that in certain extreme cases will more than offset its disadvantage of greater weight of truss metal.

The economic functions of steel trestles are treated in Chapter XXIII and those of steel arches in Chapter XXVI; and curves of weights of metal in trestles, from which the economic proportions thereof can be derived, are given in Chapter LV.

The height of concrete retaining walls at which it is economic to begin to use reinforcing metal is about (20) feet.

In respect to the economics of the medium steel specified in Chapter LXXIX, soft steel, and the standard steel of commerce, which is a mean between the two, as there is no difference worth mentioning between the pound prices of the three rolled metals, and as medium steel can properly be stressed the highest, it is evident that it is the most economic material. It is urged by some engineers that as all, or at least a portion, of the reaming may be omitted when soft steel is adopted, there is an economy in using the weaker metal; but the author maintains that either reaming or solid drilling is essential for first class work no matter what kind of metal be used, and that, consequently, the claim for economy in employing soft steel is based upon a fallacy.

The question of the economy of adopting nickel steel for bridge building is treated at length in Chapter IV.

Questions of erection often not only affect the economic layouts of crossings but also determine the character of the spans to be adopted. For instance, if the danger from washout of falsework be great, either a cantilever or semi-cantilever structure (such as described in Chapter XXV) may be better than one of simple spans, or a pin-connected structure may be preferable to a riveted one, even if the computations of cost made upon the basis of good luck in erection indicate that the contrary is the case. Again, the chance of not getting the substructure finished before high water or bad weather causes a cessation or partial cessation of work might so affect the layout of spans for a bridge as to increase materially the cost thereof; therefore, the expense involved by taking precautions to avoid possible delay would be in the nature of true economy. A case of this kind arose a few years ago in the author's practice; viz., Bridge No. 4 near Lytton, B. C., on the line of the Canadian Northern Pacific. The plans had been prepared upon the assumption that the six open-webbed, riveted spans, which were all alike, would be erected on falsework before the high water of May or June could cause any danger of washout; but the contractor in bidding, fearing that the delivery of the metal might be delayed, requested that a few of the girder members be strengthened so as to permit each span (except the one first erected) to be cantilevered from pier to pier. The extra amount of metal thus necessitated was computed; and as the bidder agreed to pay one-half of its cost, his proposed modification was accepted. It proved to be a fortunate arrangement, because the metalwork was late in arriving, and the erection had to be done by cantilevering during the high-water period.

In the proportioning of main members of bridges, and even occasionally in the detailing, small economies may be effected by choosing the regular and least expensive sections. Plates and angles are at times cheaper than channels or I-beams, and at other times more expensive. Z-bars are sometimes higher and are always difficult to obtain. Deck beams are invariably high priced, and tees are generally so. Many designers are not aware that I-beams over fifteen (15) inches deep cost one-tenth ($\frac{1}{10}$) of a cent per pound more than those fifteen (15) inches and under in depth, and that angles having one or both legs longer than 6 inches are subject to the same increase. There is a long list of special prices, too, on very small angles. Not infrequently it will be cheaper to use the larger of two small angles, even though more weight be involved; and special angles such as those of $7'' \times 3\frac{1}{2}''$ section are always more expensive than the standards, besides being more difficult to obtain. Current prices of the various sections are to found in *Engineering News* the first of each month; and a list of extras for wide plates is given on page 327 of this treatise. Since the organization of the United States Steel Corporation, the variations in pound prices of the numerous shapes of bridge

metal in this country are less than they used to be; but they are still sufficient to make a material difference in the cost of structure; whereas, for Canadian and other foreign work, very large differences may be created by the selection of the material, owing to the variation in the customs' duties. It behooves the expert bridge designer to keep posted concerning variations in metal prices and import duties for the different sections. The Bethlehem Steel Company manufactures, by means of a combination of vertical and horizontal rolls acting simultaneously, some special sections for I-beams that are exceedingly light for their strength; and, although the company asks a small extra price for such sections, it generally proves economical to employ them.

The duplication of a whole structure, or any parts thereof, effects a large proportionate saving in the shop. Of course, if two spans or other units can be made alike, entire groups of drawings are saved, and it is a large part of the function of the detail shop draftsman to duplicate individual parts and to group partially unlike members. The author remembers the detailing of two hundred and fifty-six (256) columns of the Union Loop Elevated Railroad on one sheet. The columns were not all alike; in fact, there were many different models, but the differences were so classified that they could be reduced to a system, and the whole work was very greatly cheapened thereby. By duplication, in addition to a saving in drawings, there is a saving of templets, a saving of shop supervision, a saving of the writing of shop bills, a saving of making extra material lists, a large saving in errors, and a considerable saving in the field due to the avoidance of loss of time in the selection of the proper parts; for if there is much duplication, there is much more possibility of the right part being at hand. Duplication extends into very small details; in beam work the end connections are made alike, and instead of being shown on the drawings, their numbers only are given. Likewise the templets for such end connections are made permanent; and they, too, are referred to only by number and are used over and over again. On large structures, batten plates, lattice bars, and other similar and oft-repeated elements can be duplicated with great advantage. For instance, identical lattice-bars save the resetting of the gauge on the lattice-bar punch, and also the labor of selecting in assembling the material, besides considerable expense in handling. It may at times require more material to duplicate the parts of a structure, and yet it may result in a net saving in the cost of construction; for, although the metal be ordered by the pound, if the evidence of duplication of shopwork is made clear in the drawings submitted to bidders, a lower pound price will be named.

Blacksmith work of any kind is always the most expensive work in a bridge shop, and it should be avoided to the utmost, not only because it is not commonly well done but also because it costs heavily in the drawing room, in the templet room, in the forge shop, and in punching, fitting, and assembling. If forging is essential, it should be done in du-

plicate as much as possible, so that dies may be made. The author recalls the bending of the top flanges of some through plate-girders by hand on a form at a cost in excess of seven dollars ($7) for each bend. The railroad company was induced to use a round instead of a parabolic curve. This enabled the manufacturer to prepare dies and to do the work for less than one dollar ($1) per bend, yet the saving was made possible by only a very trivial change in the form of the flange angles. Small bent plates are nearly always fashioned by hand, since they are not sufficiently duplicated to warrant the making of dies; but it is a common practice of engineers not engaged in shopwork to use forgings freely, because they do not understand how greatly forgings add to the cost of the whole work.

There is a small economy or the reverse involved in the crimping of stiffening angles for plate-girders; and the officers of the different bridge shops have widely varying ideas as to whether it is better or not to crimp them. The economy will depend upon their length and the amount of offset, for the question involved is whether the cost of crimping the ends does or does not exceed that of furnishing and putting in the filling plates. Before starting to write this chapter a number of the bridge shops were consulted on this matter of crimping, in order to obtain a consensus of opinion. One engineer replied, "We would not crimp angles for any girders on a lump sum contract no matter what the depth unless the angles were over three-quarters (¾) of an inch thick. In case side flange plates were employed, we would, of course, use crimped angles for any girder four feet deep or deeper." Another engineer answered, "If we had a contract for a bridge at a lump sum, we would crimp stiffeners on all stringers or girders three (3) feet deep or over, providing, of course, nothing else was specified." A third engineer wrote: "We always try to avoid crimping stiffeners when the clear web space between the flange angles is less than eighteen (18) inches. We, of course, would likely try to crimp stiffeners of shorter length if the flange angles were very thick and the stiffeners of light sections, if we were aiming simply to make money by putting in the less amount of material; but, on the other hand, we believe it makes a better job to use the fillers when the depth of the girder is shallow." The cost of the freight on the filling plates is often the determining factor in settling whether it is finally more economic or otherwise to crimp stiffening angles, and this feature of the question should be borne in mind by the designer. This matter of cost of freight and other transportation of metal to bridge site applies to the design of a bridge as a whole as well as to the question of crimping.

There is often a material difference between the lightest possible bridge and the most economic one, not only on account of the reduction of cost of fabrication but also because of that of erection; and the designer in order to obtain the best possible results for all cases must be well posted on all the important details of both shopwork and field work. He should know almost instinctively what is easy and what is difficult

to manufacture and to erect; and especially should he recognize when rivets can and when they cannot be driven by the various kinds of apparatus used in shop and field.

In the design of new bridges to replace old ones, the erection should be given full and thorough consideration, since a large amount of the labor of replacing the old structure under traffic may be saved if the new one have panels of such length as not to interfere with the metalwork of the old bridge. There are many other ways in which advantage may be gained by thoroughly considering the erection at the time the new structure is designed, such, for instance, as the supporting of the old stringers on advantageously located falsework until the new girders can be placed, and the shipping of the plate-girder spans riveted up complete instead of requiring that they be assembled in the field.

In all work of designing the cost of the materials at the site should be studied very carefully, since local prices will often enable the designer to effect a great saving. Where the work is scattered over a wide field, the matter of cost of materials becomes exceedingly important and often changes the type of the structure. For instance, in designing a highway bridge for the Western Coast, it should be remembered that steel stringers become very costly as compared with the lower priced wooden stringers of that country. The opposite conditions obtain in the eastern part of the United States. The prices of gravel for concrete work, or of very cheap stone, may affect the type of piers employed. The engineer should know markets even better than the contractor, but commonly he does not, and he will often demand expensive material where a cheaper one would serve his purpose quite as well. Rough averages of prices per unit in place are very apt to produce flaws in the economy of a design.

There is an economic feature of bridge building that is worthy of special mention in that it effects a large saving in first cost, maintenance, and repairs, often for a number of years. It is the designing of cantilever brackets to carry in the future wagonways, footwalks, and even street railways, and omitting putting them in until required, but providing all the rivet-holes for the future connections. In such cases, of course, the trusses must be made strong enough to carry the additional live and dead loads, and the counterbracing must be figured for both the future and the immediate dead loads.

A question sometimes arises as to whether it is more economic to support a pavement on buckled plate or on reinforced concrete. The latter is cheaper for trestles and short spans, but not for long ones. However, the deterioration of the buckled plates, due to moisture and smoke fumes, should receive adequate consideration. Moreover, the latest experience shows that very heavy concentrated live loads are liable to spring the buckled plates and break up the paving.

Some of the most modern problems in bridge economics are those due to the advent of reinforced concrete construction. For instance, in

highway bridge building there arises the general question as to whether it is advisable to adopt reinforced concrete or steel; and for spans under one hundred feet in length, when due consideration is paid to the factors of maintenance, depreciation, and repairs, the former will usually be found the more economic. In the future this limit of span-length for economy will certainly continue to increase; and probably even today it has been passed in some localities.

Another problem is whether in reinforced concrete construction it is preferable to adopt the arch or the girder type. Unless the spans are quite long, the latter will generally be the cheaper, but the former is the more æsthetic, although by curving the bottoms of the concrete girders, as was done on the Twelfth Street Trafficway Viaduct in Kansas City,* a very pleasing effect can be secured.

Another economic problem is whether to adopt a wooden or a reinforced concrete floor in a steel highway bridge; and, when danger from fire, cost of maintenance, etc., are considered, the decision should invariably be in favor of the permanent construction.

Since the late occurrence of partial destruction by fire of several large highway bridges carrying creosoted block pavement resting on creosoted planks, the question has arisen as to how much more it would have cost to rest the pavement on reinforced concrete. The layman has an idea that the amount is very small, being merely the difference between the value of the reinforced concrete slab and that of the creosoted planks; but such is far from being the case, for the large difference between the weights of the two bases adds materially to the dead load that has to be carried by both the floor system and the main girders or trusses. Some careful computations made by the author from the records of two of his bridges over False Creek at Vancouver, B. C., both of which have lately been set on fire more than once by German sympathizers, and one of which, in consequence, was severely damaged over a length of two or three hundred feet, show that the substitution of the reinforced concrete slab for the creosoted plank would have increased the first cost of the superstructure fully twenty per cent. In these days of bridge incendiaries it certainly would be good policy to employ the more expensive base and perhaps even to adopt an asphalt or bitulithic wearing surface instead of the wooden blocks, although the latter are far superior in every way except in respect to freedom from danger by fire. However, it would be difficult to start a conflagration in a block pavement that rests on a concrete base, because the air could not readily get at the wood. A fire kindled under such conditions would make very slow progress and could easily be extinguished.

In the case of a steel viaduct, the question sometimes comes up as to the economics of making the bents of reinforced concrete instead of steel;

* For description and illustration of this structure see Chapter LII.

and for heights not greater than forty or fifty feet the concrete is likely to win; but with braced towers the steel will generally prove the cheaper. In solitary bents of reinforced concrete attention must be paid to the bending effect of longitudinal thrust, and this is likely to prove an important factor in the determination of the economics of the layout.

There is an economic question to which, as yet, but little attention has been paid, viz., the comparative costs of cantilever and suspension bridges. Until 1911 nothing of any value had been published concerning the length of span at which a suspension bridge becomes cheaper than a cantilever, each bridge specialist having had a vague idea of his own concerning the question. The author for years has believed the dividing length to be in the neighborhood of 2,000 feet, but has recognized that it will vary considerably for different crossings on account of the governing conditions. If the question were one of superstructure alone, it would readily be capable of solution, but the substructure plays an exceedingly important part therein, as can be seen by the following reasoning, which, perhaps, some reader may term a *reductio ad absurdum.*

Let us assume that for a certain crossing we have determined the length of main opening at which the costs of the cantilever and the suspension types are equal and have prepared a layout for each. Then let us raise the grade on them both fifty feet and make another comparison. There would be no material change in the costs of the superstructures, but there would be in those of the substructures. The main pier costs for both types would be augmented in a similar manner, provided the back-stays for the suspension bridge retained their original inclination. However, as the inclination of these back-stays would have to be increased, the load on the columns and the main piers for the suspension bridge would be augmented thereby, increasing their cost over those for the cantilever structure. There would probably be comparatively little increase in the cost of the anchorages for the cantilever bridge, as their heights could be augmented without material addition to the volume. But the cost of the anchorages for the suspension bridge would be materially increased to provide for the additional uplift due to the greater inclination of the back-stays—then the cost of the suspension bridge would be greater than that for the cantilever layout for this length of structure, and the length for equal costs would be increased.

Let us take another example: Suppose that there are two profiles for crossings just alike, that in one the surface material is solid rock throughout, but that in the other the foundations *for the abutments* are very soft, necessitating the use of a great number of exceedingly long piles. If the opening of equal cost in the two types of structure be determined for the rock profile, it will certainly be too short for the other; because, while the soft foundation acts as no special hardship in the case of the cantilever anchorage (owing to the load thereon being vertical and compara-

tively small), it certainly would militate greatly against the suspension anchorage with its immense vertical and horizontal loadings.

In 1911 Dr. D. B. Steinman published a little book entitled "Suspension Bridges and Cantilevers—Their Economic Proportions and Limiting Spans," the main object of which was to determine the economic dividing span-length between cantilever and suspension bridges. In order to evolve a mathematical demonstration of the problem he had to make numerous assumptions more or less approximately correct. Without checking all his mathematical work, it is evident that the professor has made as fair a comparison as he could; but his assumptions were so numerous and approximate that his conclusions must be taken with a liberal allowance for variation. Dr. Steinman's conclusion on this point reads as follows:

> "The range of economic usefulness for cantilevers extends from the upper limit for the truss or arch to a span of 1670 feet. Beyond this value, the cantilever would be more costly than the suspension type, although yielding a probable profit on the investment up to a span of 2700 feet."

Dr. Steinman employed for his estimates on both types of structure nickel steel only fifty per cent stronger than carbon steel, while the author has found that it is practicable to procure the alloy with an excess strength of seventy per cent. Again, the use of nickel steel was confined to the trusses only, while the author finds that for ordinary conditions of the metal market it is economic to employ it in the floor system, especially for long spans, where it is important to reduce the dead load to a minimum. Dr. Steinman makes the difference in pound prices between nickel steel and carbon steel, erected, 2.4 cents. This ought to be too great for nickel steel of even 55,000 lbs. elastic limit, for Mr. Hodge built his St. Louis Free Bridge on the basis of 1.65 cents per pound excess.* Dr. Steinman makes only sixty (60) per cent of his long-span trusses of nickel steel, while the author adopts a percentage of seventy-five (75). In designing the anchorages for the cantilever bridges Dr. Steinman uses only carbon steel, while nickel steel will generally be more economical. All these facts affect materially the question at issue; and it is probable that if the changes above implied were incorporated, the span-length for equal cost found by the investigator would be considerably greater. In spite of the differences of opinion indicated in the foregoing, the author appreciates most highly the good and valuable work done by Dr. Steinman in the preparation of his little book. It certainly will prove of great benefit to all engineers who are concerned in the designing of long-span bridges.

Another economic question in bridge engineering that has arisen of

* The use of Mayarí steel, having an elastic limit of 50,000 pounds per square inch, at an excess pound price of only eight-tenths (0.8) of a cent for the manufactured metalwork as compared with carbon steelwork (the latest quotation from the Pennsylvania Steel Company) would affect the economic problem materially.

late years is the economics of movable spans, or the choice for any crossing between the swing, bascule, and vertical-lift types. The settlement of this question is by no means an easy matter, for it will depend greatly upon the special conditions affecting the particular crossing under consideration. When the swing span type is pitted against either of the others, the first point to determine is what proportionate length of single opening is equivalent to the two openings afforded by the rotating draw. This is a matter of personal opinion, and even in one man's mind it might vary materially for different cases. Under ordinary conditions the author believes that a single clear opening twenty-five (25) per cent greater than either of the clear openings afforded by the swing type will give equally good or better facilities for navigation, and that under the worst possible conditions the excess percentage need not be more than forty (40). Unfortunately, though, neither the author nor the designer of the bridge under consideration has anything to say about deciding this point, because the court of last appeal is always the War Department. If that department deems that the clear opening or openings suggested by the designer be insufficient, it has no hesitation whatsoever in saying so and in compelling the petitioner for approval to increase the said clear opening or openings as much as its engineers consider advisable. Up to the present time the War Department has almost always accepted plans of the author's in which the excess percentage referred to has been twenty-five or even less; but its having done so in the past is no reason for assuming that its engineers will always be willing to recognize that percentage as their maximum requirement. Accepting this settlement of the question as fixed, it is practicable to compare swing spans with bascules and vertical lifts.

In most cases when swing spans and bascules are compared the result is either a stand-off or more or less in favor of the bascule. The conditions would be unusual where the swing proves to be much more economic—for instance, where the deck is very close to the water, thus necessitating a well or wells for receiving the counterweighted end or ends of the bascule.

In almost no practicable case is the swing materially more economic than the vertical lift, unless, perchance, the opening be very narrow, the vertical clearance very great, and the depth of the bed rock small—a most unusual combination. In almost every case of comparison which has occurred in the author's practice the vertical lift has proved less expensive than the rotating draw.

Considering now bascules and vertical lifts, in most cases the economic comparison favors the latter type. It always does so if the vertical clearance is not in excess of fifty or sixty feet. If the clearance be the usual one for ocean-going vessels, viz., 135 feet, the cost of the bascule and that of the vertical lift will be equal for clear openings of about one hundred feet or, in extreme cases, one hundred and twenty-five feet. The longer the movable span, the closer the deck to the water, the deeper the bed-

rock, or the smaller the required vertical clearance, the greater will be the comparative economy of the vertical lift.

More still, perhaps, might advantageously be stated concerning "True Economy in Design," but lack of space prevents. Enough, however, has been said in this chapter to show the necessity for paying strict attention to the subject of economics in designing structures both as a whole and in detail. The reader's attention is called to a valuable paper entitled "Highway Bridges from the Investment Point of View," by C. R. Young, Esq., a Canadian engineer, published in the *Engineering Record* for March 18, 1911. While it was written specially for Canadian conditions, it is also applicable to those of many parts of the United States; and the writer's treatment of the subject is of such excellence as to make its perusal well worth while for any engineer who is interested in highway bridgework.

CHAPTER LIV

DETERMINATION OF LAYOUTS

The determination of the layout for a large structure is one of the most important responsibilities in the province of the bridge engineer; and to do the work in the most effective manner possible demands a wide experience, coupled with good judgment and the ability to foresee eventualities over a long period of years. The general idea that the best possible layout is the one which makes the first cost of structure a minimum is a fallacy; for there are many other considerations besides economy in initial expenditure that are of great importance. The following is a fairly complete list of the various items which should be carefully considered before settling finally upon the layout of grades, clearances, span-lengths, character of substructure, and type of superstructure to adopt. This is a long list, but it must be remembered that it is intended to cover all the considerations for all cases, and that, probably, only a few of the items will apply to any particular case.

List of Factors and Conditions Affecting the Layouts of Bridges

A. Government Requirements.
B. Grade and Alignment.
C. Geographical Conditions.
D. Commercial Influences.
E. Property Considerations.
F. General Features of Structure.
G. Future Enlargement.
H. Time Considerations.
I. Stream Conditions.
J. Foundation Considerations.
K. Navigation Influences.
L. Construction Facilities.
M. Erection Considerations.
N. Æsthetics.
O. Maintenance and Repairs.
P. Economics.

While there is an attempt at logic in the arrangement of the preceding list on the combined lines of natural sequence and comparative importance, it is impossible to state in advance for any particular case or class of cases which are the items that should receive the most consideration. Each item will be taken up and discussed in the order adopted in the list.

Government Requirements

In Chapter L the requirements of the United States Government regulating the bridging of navigable streams are treated at length. Neither the Federal Government nor any of the State Governments, however, con-

cern themselves with the bridging of streams that are not navigable, unless it happen that suit against the builder or the proposed builder of the bridge be instituted in either a State or a Federal Court, when, of course, the law will be concerned.

The War Department nearly always confines its attention to a few salient features of any proposed crossing of a navigable stream, viz., the span lengths, the clear waterway for navigation, the angle of skew (if the crossing be not square), the position of the movable span or spans (if there be any), the clear headway above high water for both the movable and the fixed spans, the character and the dimensions of the draw protection, and the amount of obstruction to the flow of water caused by the piers—especially those parts thereof below low water mark.

In spite of the fact that the War Department has certain rules for determining the span-lengths for crossing various navigable rivers, the said rules are more or less elastic; hence it will generally pay any consulting bridge engineer, or other engineer who intends to bridge navigable water, to consult first with the local engineer of the Government who has charge of the district in which the proposed structure is located, and later, if necessary, with headquarters at Washington, in order to settle as to what the exact requirements of the Government will be. Often by stating one's case clearly and logically one can persuade the authorities to ease up on some regulation that appears to be unnecessarily strenuous or severe. For instance, the relation between the widths of clear openings required for swing spans and bascules or vertical-lift spans is a matter that has never been finally determined by the Department, each case as it arises being solved on its own merits.

Again, if the limiting length of span set by the Government does not exactly fit a crossing, one has to put in a shorter span at one end of the bridge, or to increase equally all the span-lengths, or else to obtain permission to decrease them equally. If the decrease be small, it is sometimes practicable to obtain the consent of the Department to the adoption of the shortened span-length.

In the case that the grade of a bridge is so low as to bring the clearance line too close to the elevation of high water to meet the Government requirements, it is sometimes possible to persuade the Department to permit an encroachment; but to do so would certainly be bad policy, for the limit set by the United States Engineers is adjusted about right to provide safety from passing drift.

In respect to the position of the movable span, the broad statement can be made that its mid-length should coincide with the deepest part of the channel; but there are occasional exceptions to the rule, notably when the channel is not permanent, or where it can advantageously be shifted by a little dyking. Permission to do such shifting and to locate the movable span accordingly would have to be obtained from the War Department. The latter may have something to say about the angle

of skew, as the United States Engineer Corps always advocates a square crossing, if it be practicable; hence the bridge engineer who desires to obtain approval for a bridge on a skew of any magnitude must be prepared to show good reason for his request; and even then it may not be granted, because, like the author, the Government engineers look upon a skew bridge as an abomination.

While the Department does not pay much attention to the character of the draw protection, it is likely to insist that it be not omitted and that its dimensions be satisfactory.

Ordinarily, also, it does not concern itself with the dimensions of the substructure; but sometimes, especially in case of a skew bridge, objection is raised to placing too much rip-rap around the piers and thus obstructing the flow of water in the channel.

Grade and Alignment

In most cases the grade and the alignment of the railroad or travelway are determined before the bridge engineer is called in, but sometimes it is otherwise; and there arise occasionally conditions which compel a conscientious bridge specialist to insist upon a change in either the grade or the alignment—or in both. The ideal way to adjust the grade on a structure is to carry it over unbroken and, preferably, level, thus avoiding either a sag or a hump, as either of these objectionable conditions involves loss of power due to the climbing of unnecessary grades. Again, any great sag causes traction stresses and a shock that might better be avoided, if practicable. The ideal alignment for a structure is not only to have it on tangent throughout its entire length, but also to continue the said tangent quite a distance away from the bridge at each end. Sharp curves constitute an invitation for derailment; and a derailment on a bridge or near the end of one is liable to prove disastrous. A reverse curve on a structure or on an approach thereto is not permissible. Where two curves in opposite directions come close together, there should be a stretch of tangent between them; and when this tangent is on a bridge, it should be made as long as possible. Sometimes it is entirely impracticable to avoid curvature on bridges and their approaches, as in the case of a railroad following the course of a river that runs between high banks and having to cross it from time to time in order to avoid heavy excavations and tunnelling. In such cases curves on the approaches are unavoidable, and often it is necessary to put a part or even the whole of the structure itself on curve. Such a general condition existed on the line of the Canadian Northern Pacific Railway as it followed up the Fraser and the Thompson rivers, crossing them nine times with only one structure entirely on the square.

In some skew crossings, especially when the obliquity is small, it is permissible to square the piers to the structure, thus saving considerable

masonry; but this practice is not always advisable because of the damming of the water by the large area of the substructure that is opposed to the current.

The layout of any bridge on a curve, or which has its approaches on curve, is greatly affected by the curvature, in that it has a tendency to shorten the span lengths in the effort to avoid excessive width of superstructure and undue increase in length of piers.

Geographical Conditions

The layout of a bridge is sometimes influenced to a certain extent by its geographical location, because a structure suitable for the heart of a city might not be appropriate in a country district, and vice versa. Generally the variation involved would be a question of æsthetics, or possibly one of flooring, for sometimes it is necessary to cover over the deck of a railroad bridge so as to permit it to take care also of highway traffic. In mountainous districts where the transportation of large, heavy pieces is either very expensive or altogether impracticable, the layout would be governed by this condition.

Commercial Influences

The principal commercial consideration that will affect the layout of a bridge is the amount and character of the traffic of which it will have to take care. If there is a variety of traffic, such as steam railway, electric railway, wagon, and pedestrian, considerable attention must be paid to the question of how best to take care of all probable combinations of the different kinds. Much money can be saved for a client by a bridge engineer who knows how to handle the question; and much can be wasted by one who is not properly posted on this important subject. An indisputable proof of the correctness of the latter statement is furnished by the notorious case of a proposed bridge to cross the Second Narrows at Vancouver, B. C. In that layout three railway tracks were adopted where two would have served the purpose equally well, with the result that the estimated cost of the structure was increased about seven hundred and fifty thousand dollars, and the project, in consequence, was either killed or relegated for consummation to the dim and distant future.

Property Considerations

Property considerations sometimes have a far greater effect on the layout of a structure than is at all legitimate. For instance, in the case of the Northwestern Elevated Railroad of Chicago, engineered by the author in the early nineties, certain high prices for land caused the company to lay out such a crooked line as to interfere materially with the attainment of a satisfactory train velocity. Refusal of property owners to

allow the construction of piers or pedestals on their land will often oblige an engineer to adopt an unduly long span or spans, or even an entirely different type of construction from the ordinary. Again, the necessity for occupying a certain city street will sometimes change entirely the character and layout of an approach to a bridge, and it might affect even the layout of the bridge itself. The method of crossing a railroad track at the entrance to a bridge might alter fundamentally the type of structure, a low bridge with an opening span being adopted if the crossing be at grade, and a high bridge with fixed spans if it be overhead. Public improvements sometimes cause material modifications of plans for proposed bridges; and even projected improvements with prior rights are liable to cause troublesome interference. The author has lately encountered obstructive opposition of this nature on a big bridge project upon which he is at present engaged.

General Features of Structure

The question of whether through, deck, or half-through truss spans or girders are adopted is one that will radically affect the layout, but mainly in the line of economics, because deck structures in most cases involve a saving of expense in both substructure and superstructure, in that the piers are shorter than those for through or half-through spans, and, generally, the spans are narrower, thus causing a saving of metal in both the cross-girders and the lateral bracing. The clear headway required, especially for short spans, is likely to influence the layout more or less.

The possibility of using buried piers and protecting the feet of the embankments near them by rip-rap will not only affect the physical appearance of the bridge, but also it will modify the economics of the crossing.

In case a bridge is to cross a navigable stream, the layout of spans will depend primarily upon whether a swing, bascule, or vertical-lift span is adopted for the opening. If a swing is employed, it will generally require an expensive draw protection, while for a bascule or a vertical lift some comparatively inexpensive dolphins, either with or without cheap fender walls of sheathed piles, will suffice.

The possibility of building an arch, a cantilever, or a suspension bridge instead of a simple span structure would affect the layout in many ways—physically, æsthetically, and economically.

Again, the material adopted for construction—whether masonry, concrete, steel, or timber—will have a similar influence.

The matter of shore protection is not likely to affect directly the layout for a bridge, although its use certainly does increase the total cost; but it might be the reason for shifting the crossing to a location where the bank is better protected by nature against scour.

Finally, the layout is affected by the character of the approaches; for they may be of earth embankment, timber or pile trestle, steel viaduct, or reinforced-concrete girders or arches.

Future Enlargement

The possibility of future enlargement of structure ought to receive consideration; and if it be decided that it is at all probable, a study of the layout should be made so as to determine how best to accomplish such enlargement when the time comes for so doing. The points to consider are whether it will be best to build an entirely separate new bridge close alongside, or to put a double-track superstructure on the old, single-track piers by enlarging them or expanding their tops, or, at the outset, to put in large piers and build the superstructure in such a manner that the trusses can be doubled in the future.

Time Considerations

The time allowed for completing the substructure or the superstructure or the whole bridge may affect the layout, for it is understandable that a certain type of structure could be built in a certain limited time while another type of structure could not. Again, the length or shortness of the working season that is entirely free from danger of washout of falsework could be a sufficient reason for changing materially the layout—for instance, by necessitating pin-connected spans instead of riveted ones.

Stream Conditions

The various influences of the stream that is to be crossed are more potent than most other factors in affecting the layout. The high water and the low water elevations are important features in the designing of the piers; the amount and character of the drift determine the minimum vertical distance between high water and the bottom of the superstructure, and, therefore, aid in settling the pier height; and the amount and consistency of the passing ice constitute an important factor in the design of the piers, especially in respect to their length and the character of their end finish; and any increasing of the cost of the piers tends, for economic reasons, to lengthen the spans.

The clear waterway required to pass the probable maximum flood, as determined in Chapter XLIX, will often settle the total length of structure; and it may result in raising the high water mark that was determined in some other manner. The profile of the river-bed and the probable scour of the materials of which it is composed are likely to affect the layout, especially if the piers require expensive protection of mattress work and rip-rap to check the said scour. The frequency and extent of the floods will influence the cost of building the piers—and hence also the determination of the layout—as will also the questions of rise and fall of tides, velocities of the passing water, reversal of current, and the existence or possible future building of levees.

A most important factor is the possibility of the permanent shifting

of the channel from one side of the river to the other. If this possibility exist, one of three things must be done, viz.: first, two movable spans must be provided; second, some effective method of retaining the channel in one position must be arranged for; or, third, the design must be so made that any fixed span of the structure may at any time be converted into a vertical-lift span.

Foundation Considerations

Important also in the determination of layout are the character and the depth of the substructure foundations. The deeper the piers have to go the longer will be the economic lengths of the spans. Again, the more difficult it is to penetrate the materials overlying the bed-rock or final foundation, the greater the cost of the piers, and the longer the economic spans. The ultimate depths to foundation and the materials to be penetrated determine what process of sinking to adopt; and as the cost of the substructure depends upon the said process, so also will the layout.

Navigation Influences

The influences of navigation that are likely to prevail during the time of the contractor's operations may be of such moment as to affect more or less the design and the layout of the structure; although this is not very likely. Again, the possibility in the future of greatly augmented river traffic may influence the type of movable span adopted.

Construction Facilities

The availability or otherwise at the bridge site of sand, gravel, concrete-stone, a machine shop for repairs, and a reliable source of supplies for the work and workmen, the accessibility or the contrary of the site from the nearest railroad depot or siding, the length and difficulty of wagon-haul or other means of transportation of materials and supplies, the facilities for securing and retaining labor, and the availability of supplies of timber and piling all affect greatly the cost of the substructure and to a minor degree that of the superstructure—hence also the layout of spans and piers.

Erection Considerations

The difficulties that may be anticipated for erection, and the method thereof finally adopted, whether by falsework, cantilevering, semi-cantilevering, or flotation, are important factors affecting the layout of the structure, as are also the questions of the maintenance of traffic and the replacement of an existing bridge.

Æsthetics

Too often the question of æsthetics is totally ignored; but when it is given proper consideration, it may cause modifications in span lengths,

truss dimensions, and shapes of piers. How much extra money it is legitimate for a bridge engineer to spend for the purpose of beautifying a structure is a mooted point. It depends greatly upon the designer's appreciation of the beautiful in nature and in art, as well as upon the elasticity of the client's purse and the extent of the influence upon him exerted by his consulting engineer. Generally speaking, the best layout for all the other ruling causes is the best also for æsthetic reasons; but there are cases when a little extra expenditure of money, time, and brains will secure great improvement in appearance; and in such cases the beautifying of the construction should, if possible, be accomplished.

Maintenance and Repairs

The cost of maintenance and repairs as well as that of operation may sometimes be a vital consideration affecting the layout of a structure. For instance, when the Jefferson City highway bridge over the Missouri River was about to be built, the bridge company, in spite of the author's forcible remonstrance, let the contract for the structure on the basis of a high bridge with a long and expensive timber trestle approach. Later they were convinced that the annual expense of maintaining the said trestle would be so great as to consume more than the total net income from traffic receipts; hence they had to change to a low bridge design.

Economics

From time to time an engineer encounters a bridge problem in which the controlling factor in the layout determination is really that of economics, and then he is happy; for, comparatively speaking, the case is a simple one. By making the cost of each pier equal to one-half the cost of the trusses and lateral systems of the two spans which it helps to support, the greatest possible economy will be obtained. A case of this kind occurred in the author's Canadian Northern Pacific Railway bridge across the North Thompson River, near Kamloops, B. C. As shown in Fig. 31*aa*, the structure consists of a number of deck, plate-girder spans, one of which is lifted so as to permit of the passage of small river steamers at certain high stages of water.

The requirements of æsthetics often conflict with those of economics; for it would not look well to let the span lengths change backward and forward, perhaps, to suit the vagaries of an unusual bed-rock profile; hence it is best in many cases to compute the economic span length for average conditions of pier cost and to use one length instead of several. It will generally be found that such an arrangement does not involve any extra expenditure worth mentioning when the cost of structure for that layout is compared with that for the truly economic one. The question of economics, however, cannot be finally settled by adopting simply that structure for which the initial cost is a minimum; because, as pointed out

in Chapter LIII, the truly economic bridge is the one for which the sum of the first cost and the capitalized annual cost of operation, maintenance, and repairs is a minimum.

As a conclusion to the general subject under discussion, in order not to discourage young engineers, it might be well to state that any designer who, when determining the layout for any large and important bridge. can and does give full and due consideration to all the factors treated in this chapter, is truly worthy to be termed an expert bridge engineer.

CHAPTER LV

WEIGHTS OF STEEL SUPERSTRUCTURES

This chapter contains a large number of diagrams of weights of metal per lineal foot of span compiled in the author's office during the last quarter of a century by the expenditure of much time and money and through great effort. They have been thoroughly revised so as to agree with the specifications of Chapter LXXVIII. In addition to the said diagrams there are indicated numerous methods of finding the weights of metal for various parts of bridges when the weights of the corresponding parts of somewhat similar bridges are given. The said methods consist in applying certain transformation formulæ; and these are of two kinds, viz., one in which the span remains constant and the applied load per lineal foot varies, and the other in which the load per lineal foot remains constant and the span length varies. In case that both the span length and the load per lineal foot vary, the effect of one variation is first computed, and then the resulting weight is modified because of the other variation.

At the end of this chapter there are presented eleven examples of how to utilize the numerous curve-diagrams herein given; and they were so selected as to be typical of all the various weight-calculation problems which are likely to occur in a bridge engineer's practice. The reader who expects ever to utilize any of these diagrams is advised to peruse the entire chapter carefully and to check the numerical calculations of all the examples, in order that he may accustom himself to the rapid computation of weights of metal in bridges and trestles of all kinds and for all classes of loading.

In general the diagrams submitted are for railroad bridges, but some of them are specially for highway bridges, and others apply to both classes of structures. In no cases are the weights of rails or hand-rails included.

Single-Track Railway Bridges

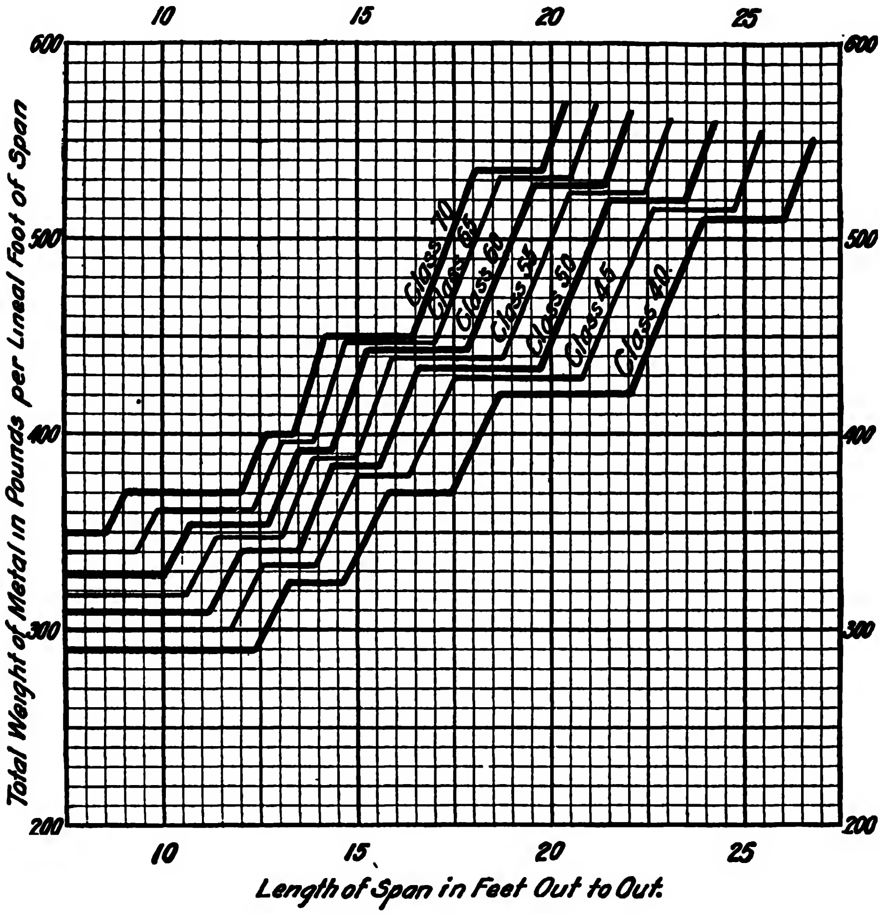
The following explanation of the diagrams will be needed:

In rolled I-beam spans there are four lines of I-beams per track.

In plate-girder spans cast-steel pedestals are employed for spans below 50 feet and cast-steel shoes and rollers for spans of 50 feet and over. No bottom lateral system is used for spans below 70 feet. In half-through spans there are four lines of I-beams per track acting as stringers.

In truss spans the weights given for the floor system include those

of the stringers, stringer bracing, end stringer brackets, and intermediate and end floor-beams. There are two lines of stringers spaced seven (7) feet centres. In respect to the metal on piers, the pedestals and the bases are of cast steel, and the weight of the pedestal pins and their nuts



NOTE.—Four beams per track used.

FIG. 55a. Single-track-railway, I-beam Spans—Total Metal in Span.

are included in the weights given by the curves. In respect to the lateral system, the bottom laterals of through spans and the top laterals of deck spans are of two-angle section in the form of a T with transverse single-angle struts between stringers to take up the effect of train thrust. The top laterals of through spans and the bottom laterals of deck spans are of four-angle I-section laced. The portal bracing is of the double-plane type.

Figs. 55*a* to 55*q*, inclusive, give, for single-track railway bridges, the weights of metal per lineal foot of span for rolled I-beam spans; deck

plate-girder spans; half-through plate-girder spans; through, riveted, Pratt-truss spans; through, riveted, Petit-truss spans; deck, riveted, Pratt-truss spans; through, pin-connected, Pratt-truss spans; and through

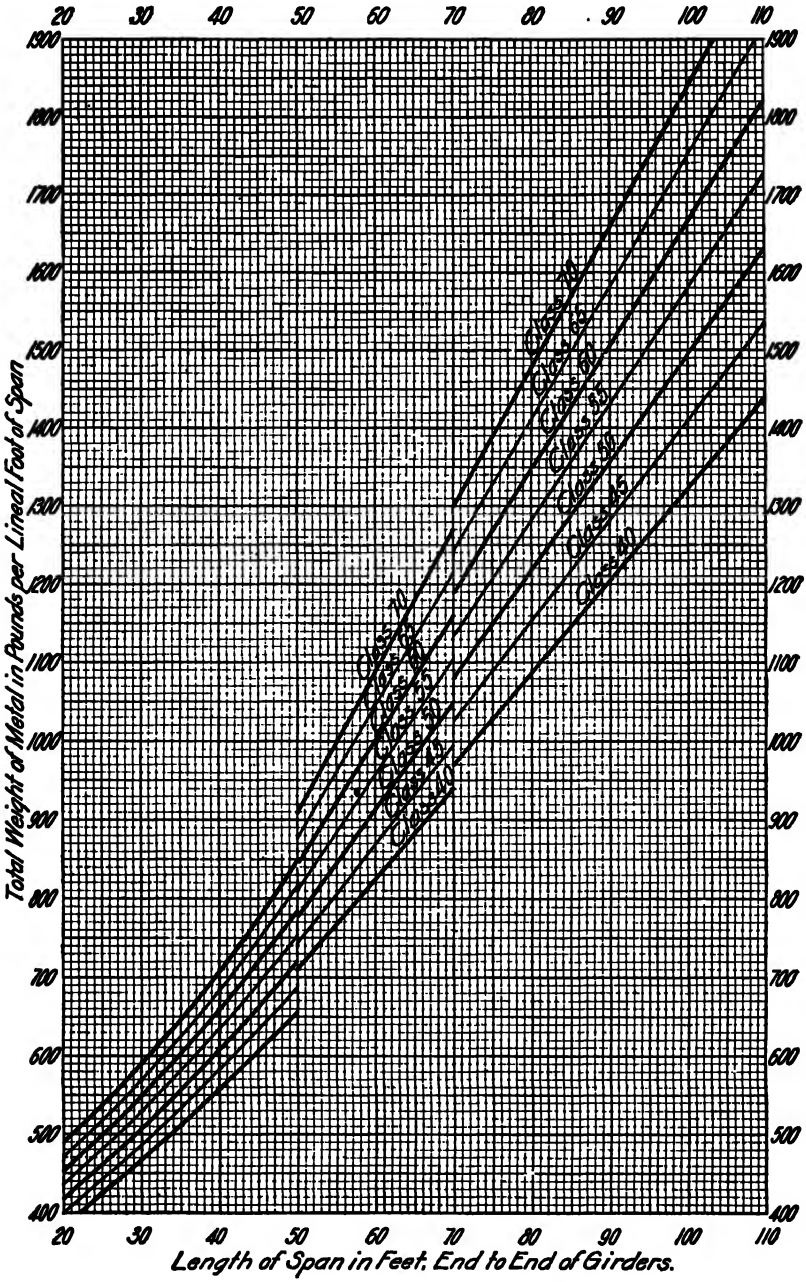


Fig. 55b. Single-track-railway, Deck, Plate-girder Spans—Total Metal in Span.

pin-connected, Petit-truss spans. In truss spans there are separate diagrams for the floor system, the lateral system, the trusses, "on piers,"

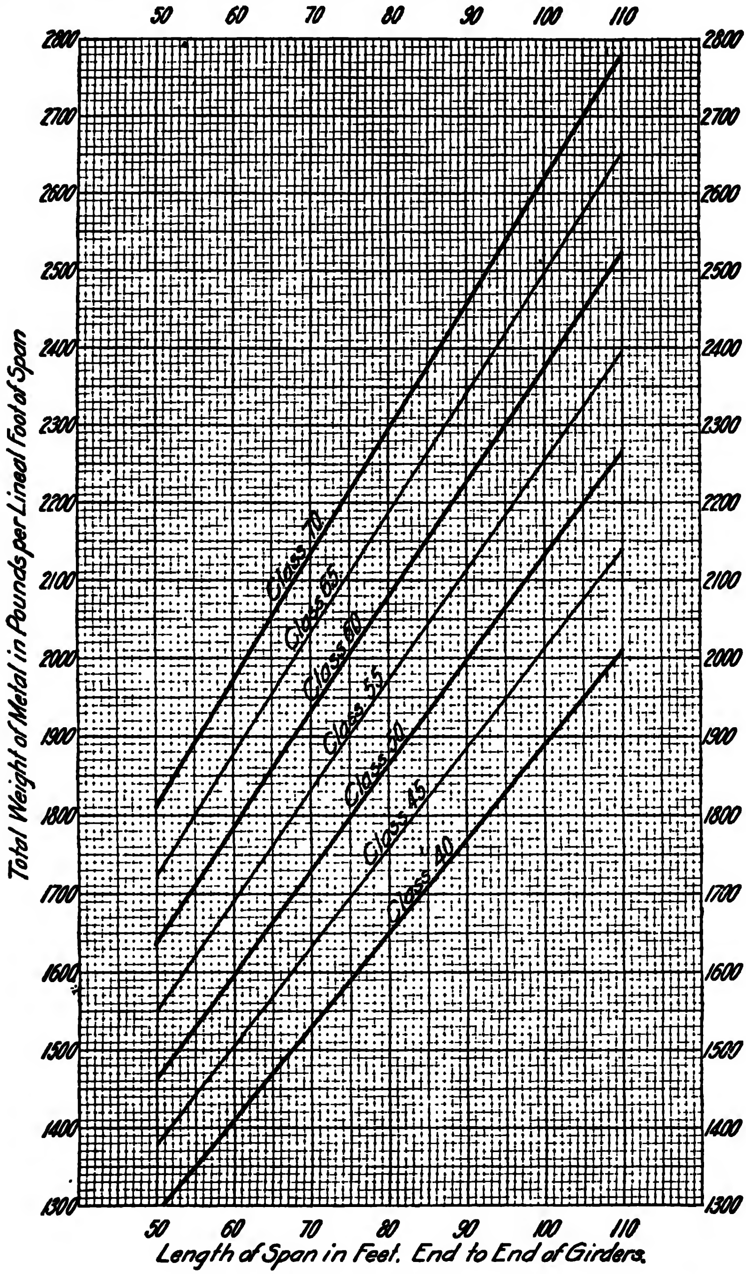


FIG. 55c. Single-track-railway, Half-through, Plate-girder Spans—Total Metal in Span.

and a combination of the four groups giving the total weight of metal per lineal foot of span in the structure. Fig. 55f gives the percentages for

details to be added to the total weight of metal in the main sections of the truss members, figuring their lengths from centre to centre on the

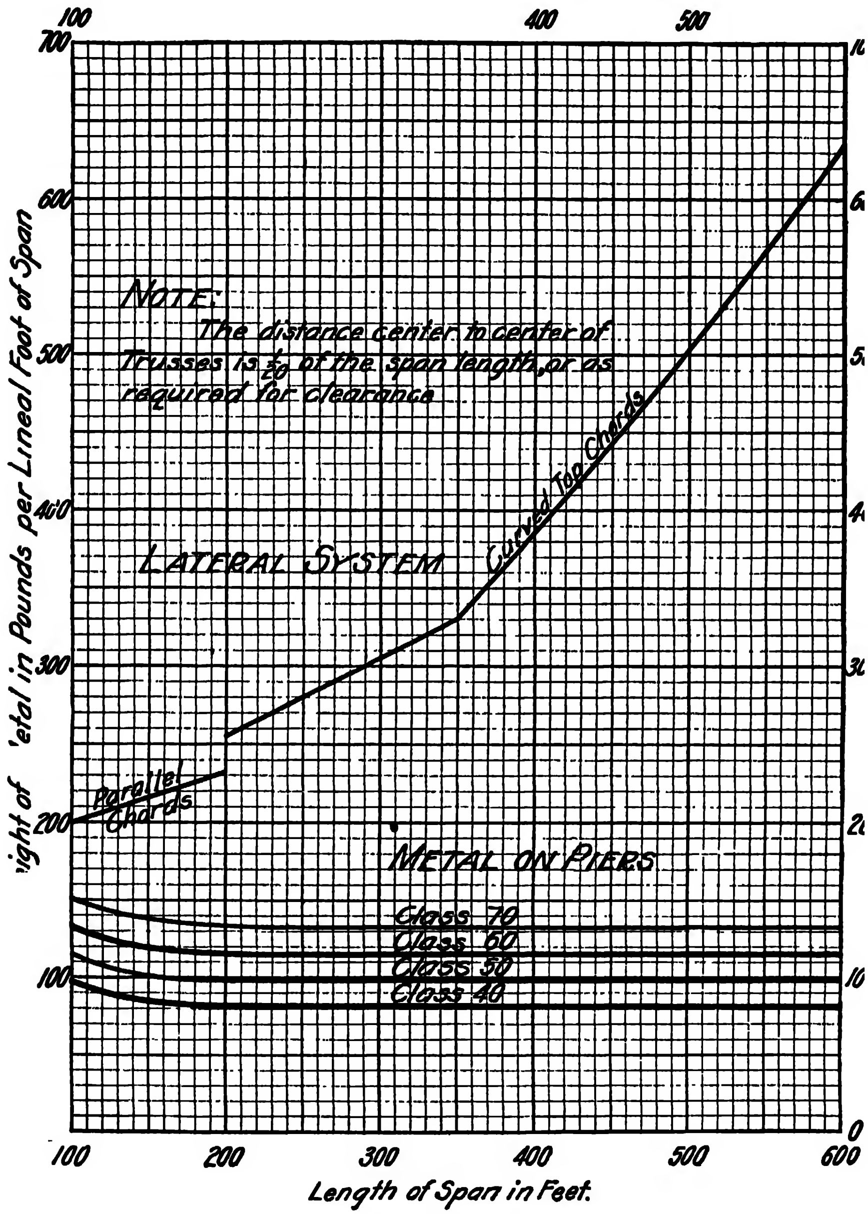


FIG. 55d. Single-track-railway, Through, Truss Spans—Metal in Laterals and on Piers.

skeleton diagram and not from the actual lengths of metal. This is much more convenient, because the determination of the exact lengths of the members necessitates considerable extra work for the computer. Should,

however, anyone desire to use the actual lengths, all the percentages given by the curves are to be increased by two.

Fig. 55j involves the use of "double-tracing" curves, hence it may

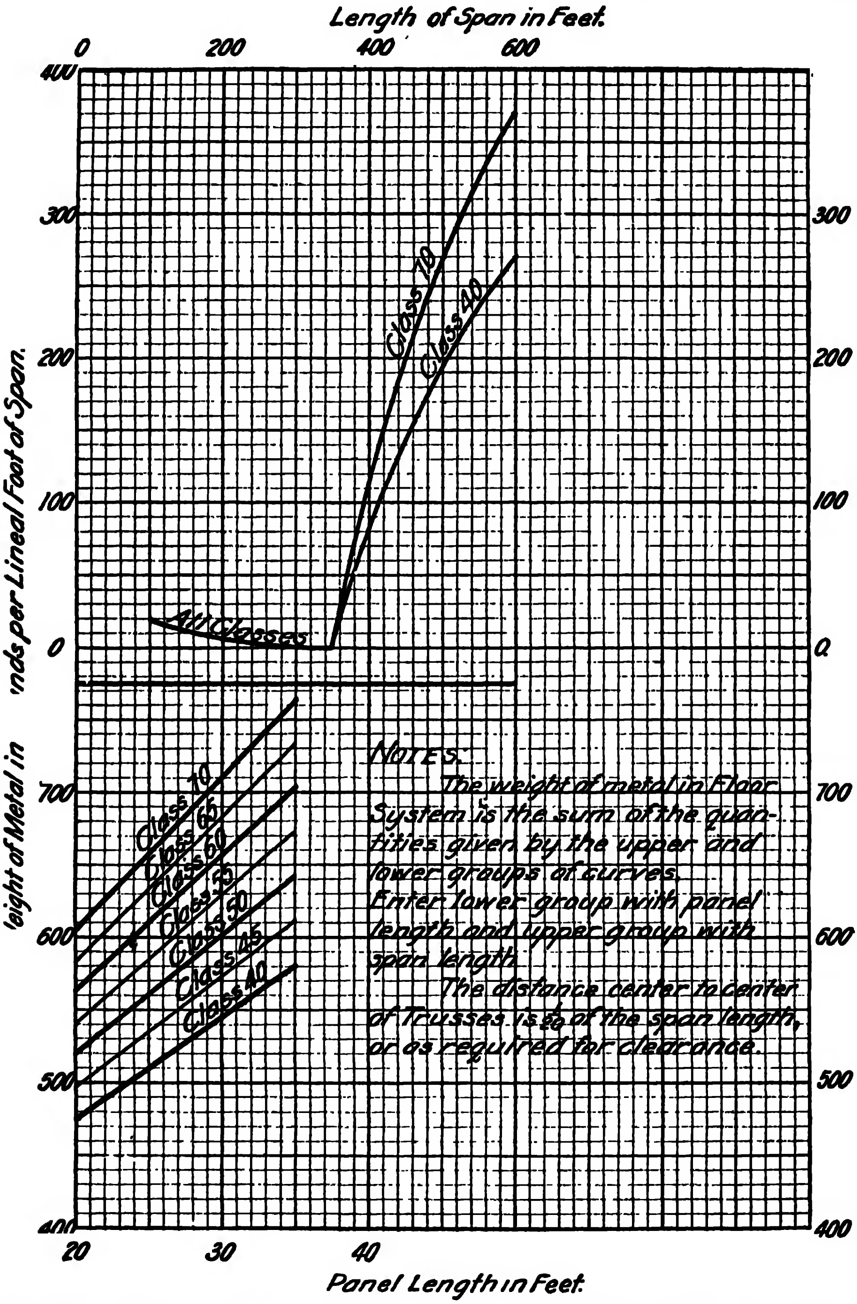


FIG. 55e. Single-track-railway, Through, Riveted, Truss Spans—Metal in Floor System.

need some explanation. To employ it, first find the panel length near the lower left-hand corner on the exterior vertical line, then trace horizontally to the curve which corresponds to the distance from centre to centre of trusses, thence vertically up to the curve which indicates the class of loading, and then horizontally to the left until the outer vertical

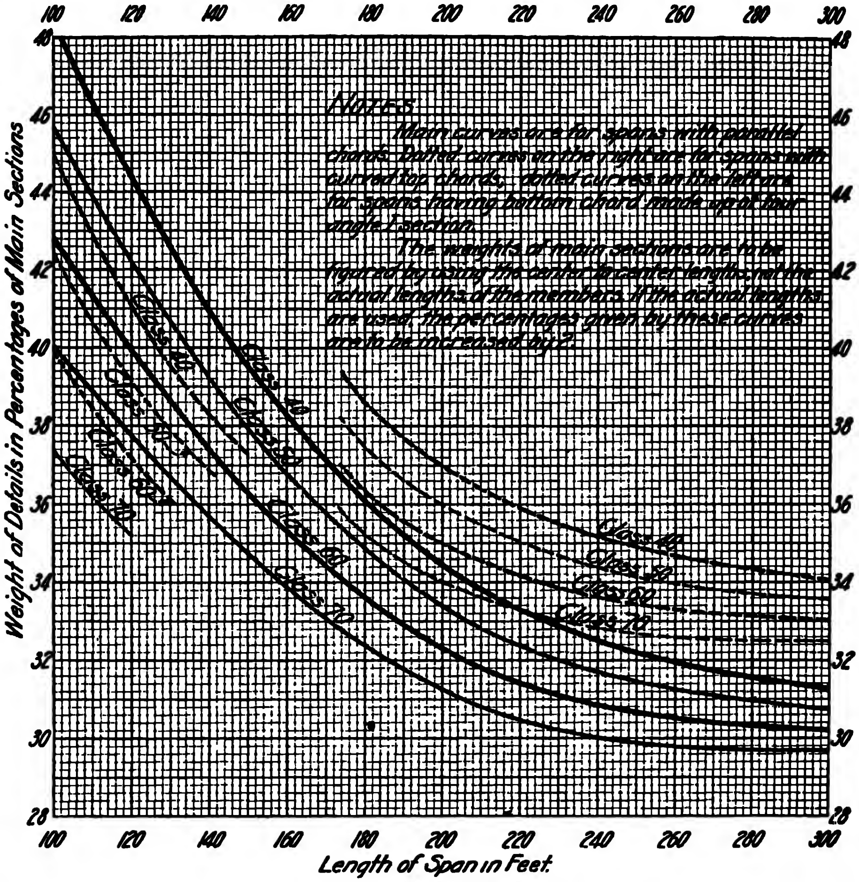


Fig. 55*f*. Single-track-railway, Riveted, Pratt-truss Spans—Percentages of Metal in Truss Details.

line is reached. On that line the reading indicated will give the weight of metal in pounds per lineal foot of span for the floor system of the bridge. This double-tracing method is very economical of space, for it obviates the necessity of reproducing many individual diagrams; and it makes the work of interpolation much easier.

Double-Track Railway Bridges

Figs. 55*r* to 55*dd*, inclusive, give for double-track railway bridges the same information as was previously described for single-track railway bridges, with the exception of the deck truss spans; hence they require

no further explanation, except that the bottom lateral diagonals of all truss spans are composed of four angles laced in the form of an I, that the weights for double-track, deck, plate-girder spans are just twice as great as those for the corresponding single-track spans, and that the weights for

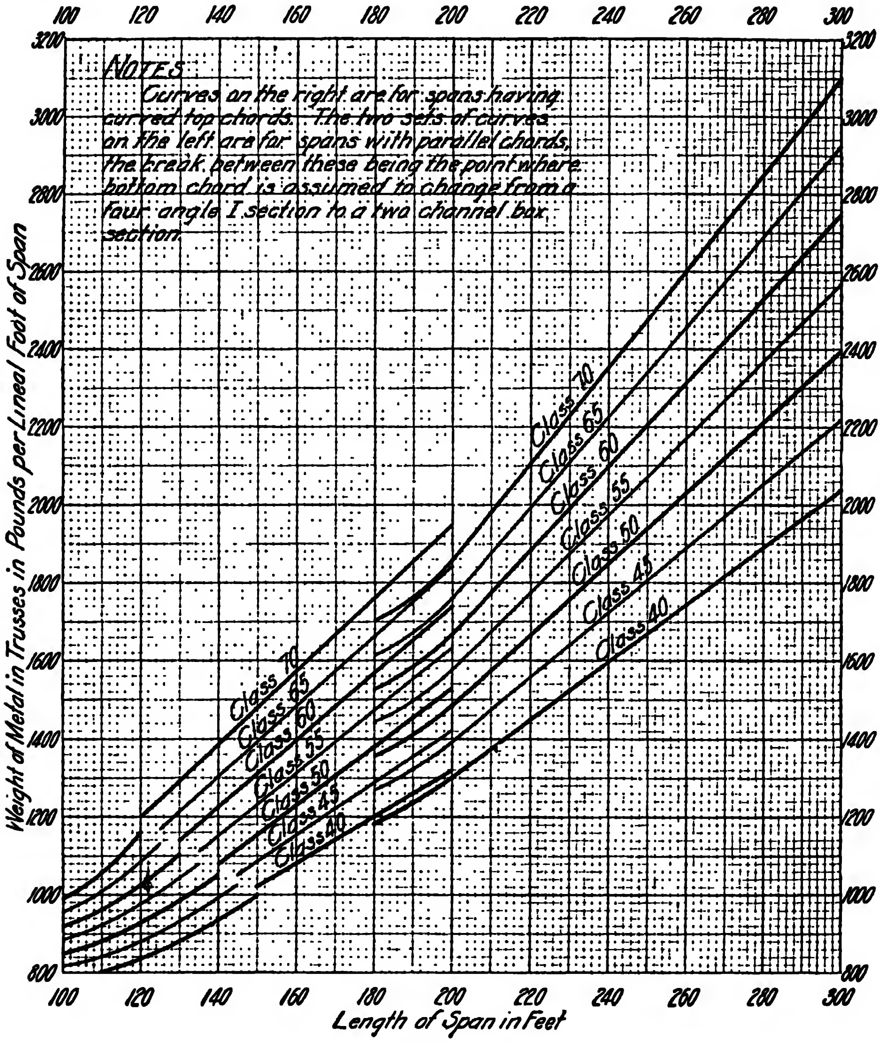


FIG. 55g. Single-track-railway, Through, Riveted, Pratt-truss Spans—Metal in Trusses.

half-through, plate-girder spans are less reliable than the other records because the restrictions in respect to vertical distance between clearance line and base of rail will modify materially the weight of both the floor-beams and the brackets that stiffen the top flanges of the main girders.

PERCENTAGES OF DETAILS FOR TRUSSES

Referring to Figs. 55*f* and 55*u*, which give the percentages to add to the nominal weights of main members of riveted spans in order to allow

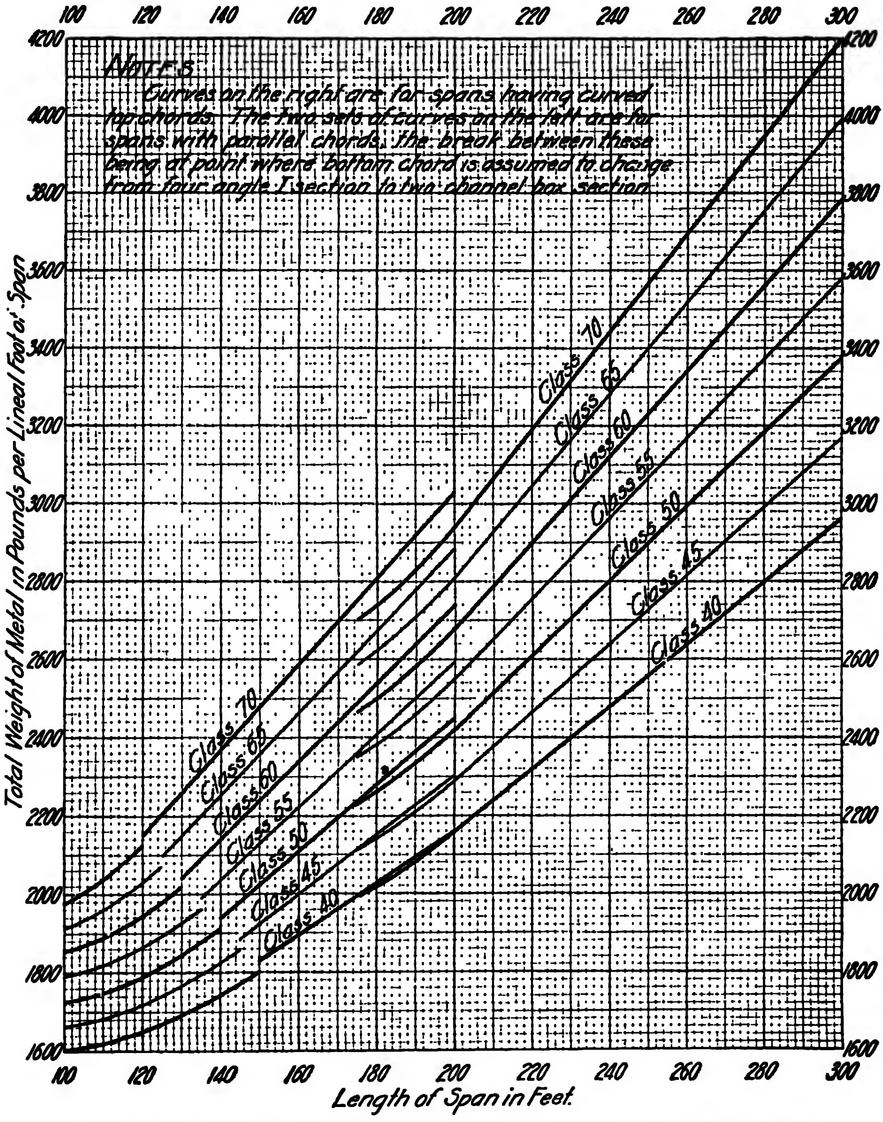


FIG. 55*h*. Single-track-railway, Through, Riveted, Pratt-truss Spans—Total Metal in Span.

for the details, it will be seen that the heavier the loading the smaller is the percentage. This is true within the limits of the diagrams, which extend only to spans of 300 feet. It will be noticed also that most of the curves become horizontal. Were they continued beyond the 300-foot

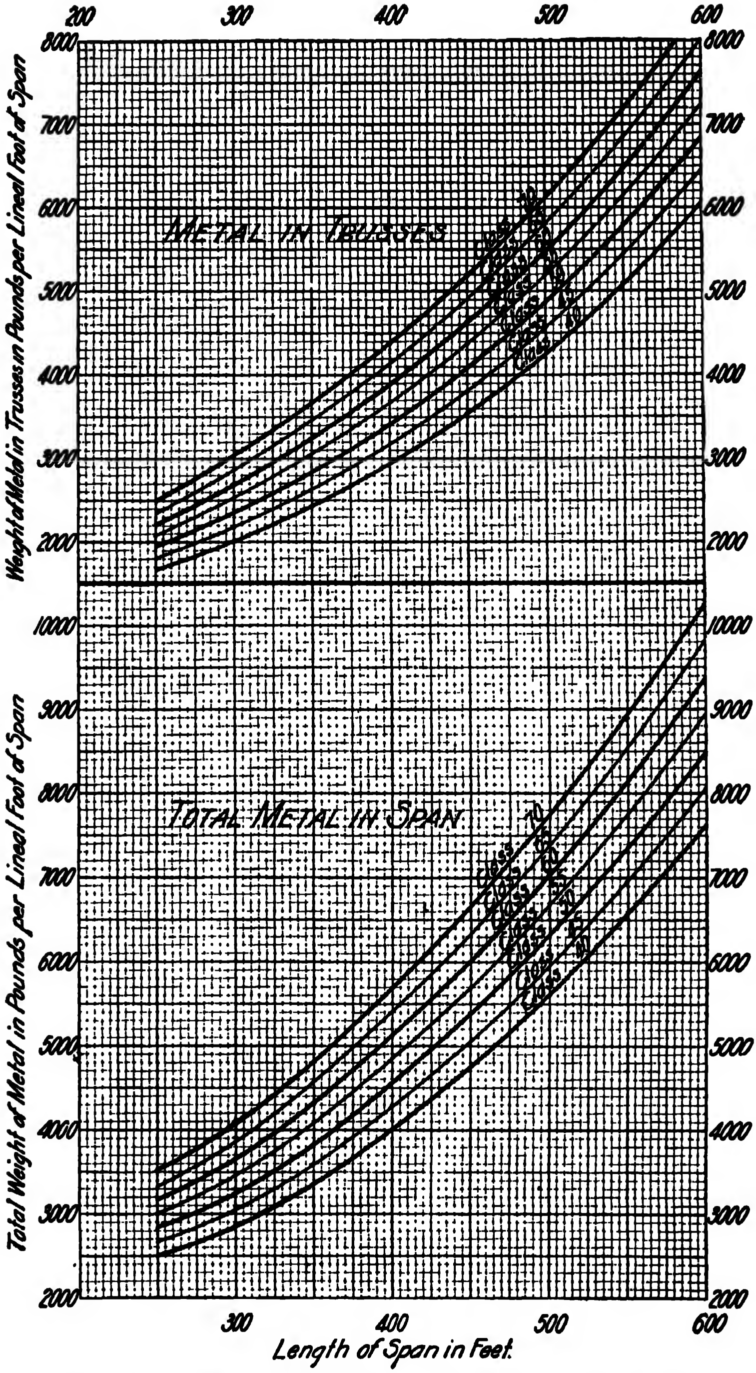


Fig. 55i. Single-track-railway, Through, Riveted, Petit-truss Spans—Metal in Trusses and Total Metal in Span.

limit, they would all sooner or later begin to rise, and eventually might indicate percentages as great as forty-five or possibly even greater. Strictly

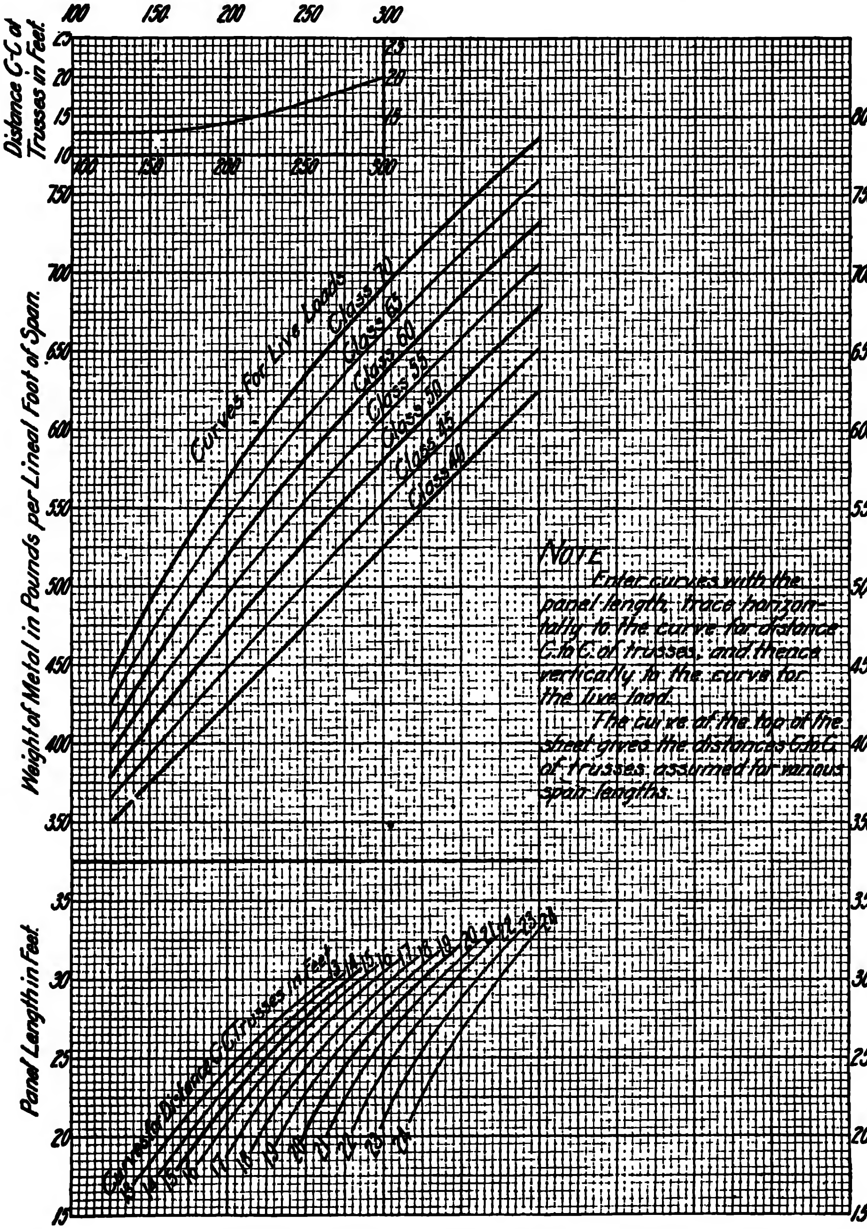


Fig. 55j. Single-track-railway, Deck, Riveted, Pratt-truss Spans—Metal in Floor System.

speaking, this percentage of detail for riveted spans is not so much a function of the span length as it is of the total weight of metal per lineal foot.

For light, short-span bridges the percentages run high, mainly because the thicknesses of the connecting plates are greater than pure theory would call for, and because good proportioning demands that details, such as

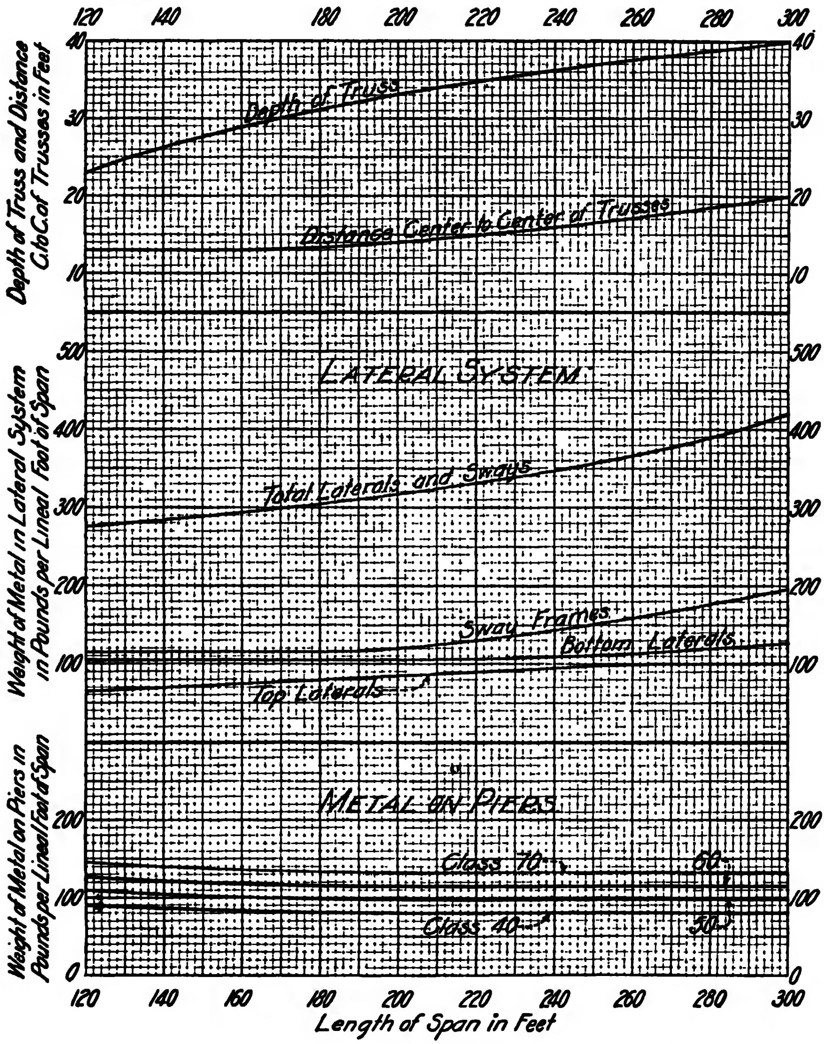


FIG. 55k. Single-track-railway, Deck, Riveted, Pratt-truss Spans—Metal in Laterals and on Piers.

lacing and batten plates (and often even the connecting plates), have proportionately larger sizes than they would have in heavier structures. But as the weight of metal per lineal foot increases, either because of greater span length or on account of heavier loading, the proportioning of the details is governed more and more by theoretical considerations, and there is less apparent extravagance of metal in detailing; hence the per-

centage diminishes until the said apparent extravagance reduces practically to zero, when the curve becomes horizontal. For a short distance it

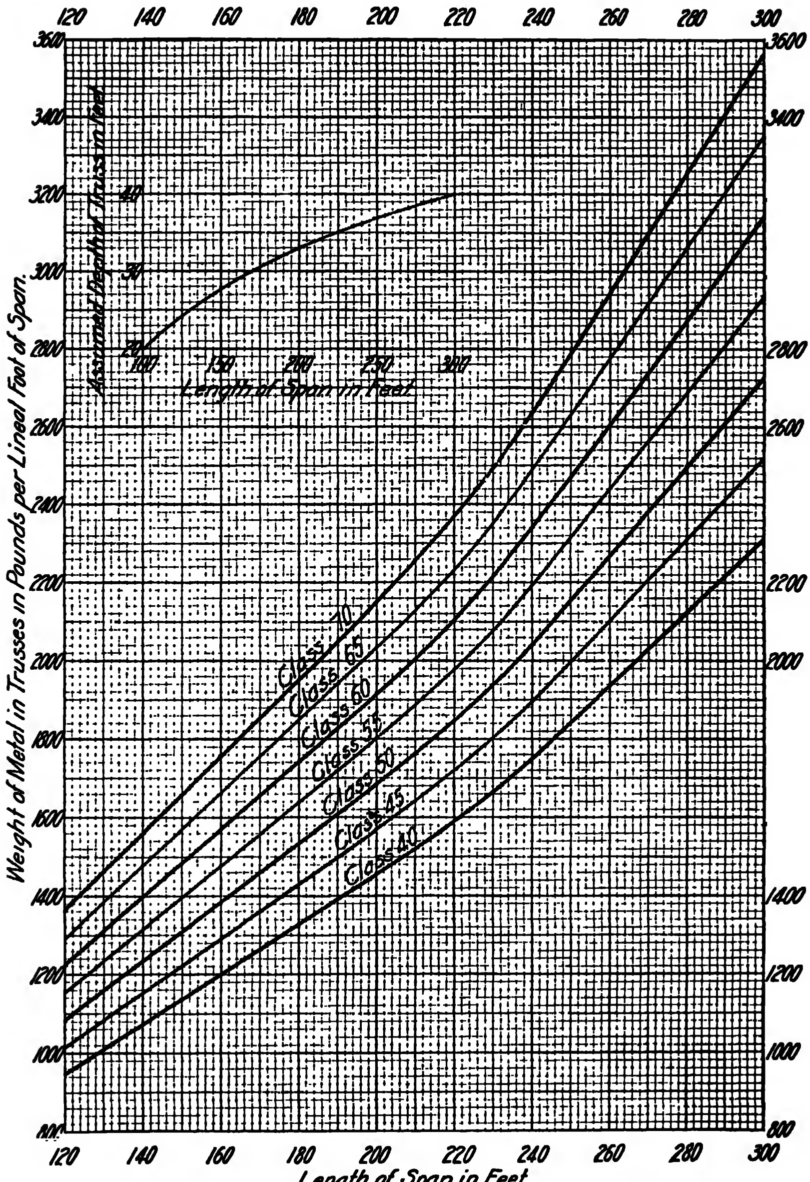


FIG. 55*l*. Single-track-railway, Deck, Riveted, Pratt-truss Spans—Metal in Trusses.

may remain so, but presently there arise conditions which cause an increase in detailing, such, for instance, as the necessity for using diaphragms in compression members, the great number of splices required in the web

plates of the chords because of the inability to secure long, deep plates, and the piling up of connecting plates at the intersections; then the curve begins to rise and continues to do so as the spans become heavier and the

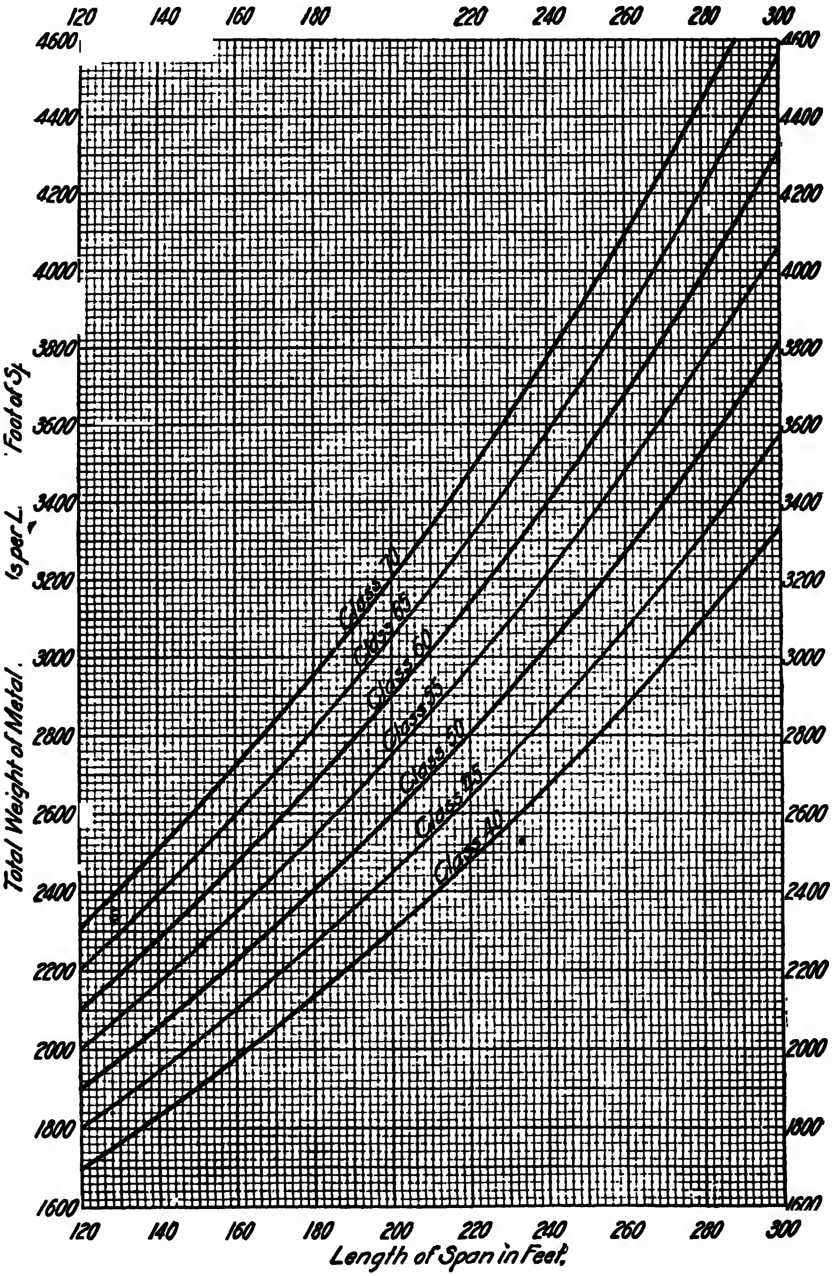


FIG. 55*m*. Single-track-railway, Deck, Riveted, Pratt-truss Spans—Total Metal in Span.

main details more clumsy. The adoption of closed box compression chords would tend to reduce the percentages somewhat, but that style of detailing has not yet come into vogue. For riveted trusses it is impracticable to

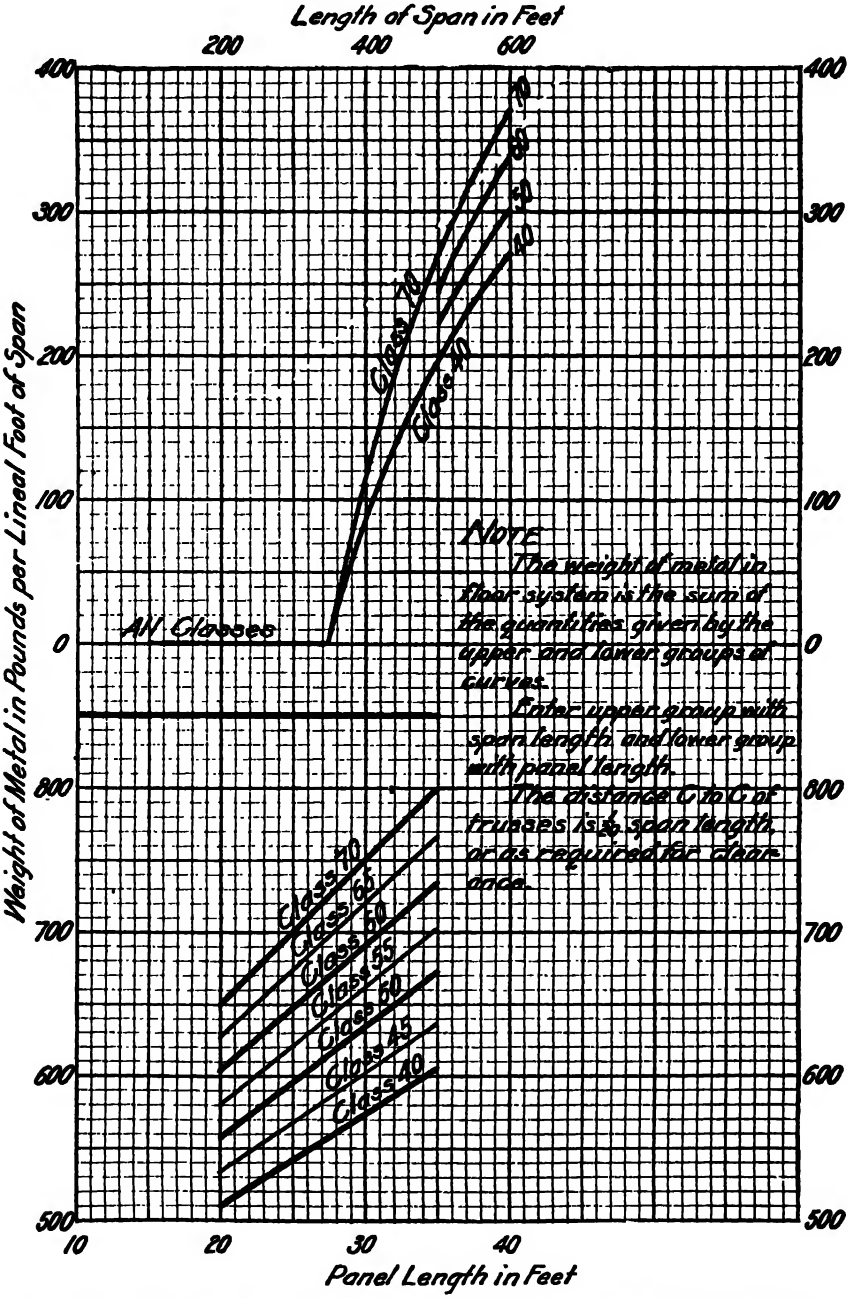


FIG. 55n. Single-track-railway, Through, Pin-connected, Truss Spans—Metal in Floor System.

diagram the percentages for details by the span length so as to suit all cases of loading, but the curves in Figs. 55*f* and 55*u* are reliable as far as

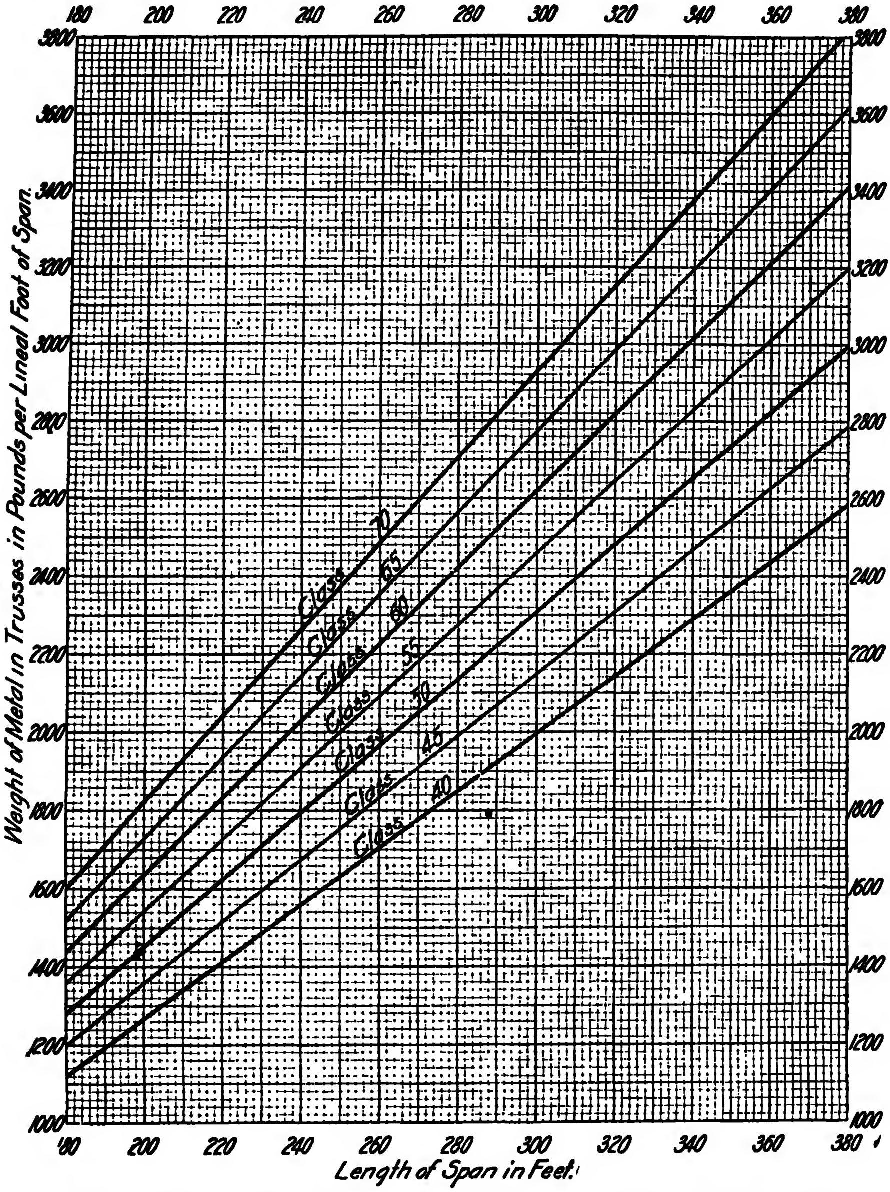


FIG. 55*o*. Single-track-railway, Through, Pin-connected, Pratt-truss Spans—Metal in Trusses.

they go. In the former diagram, which covers single-track structures, the author would suggest that after 300′ for Class 70 or 400′ for Class 40 the curves be assumed to rise gradually from about 33 per cent up to 40 per

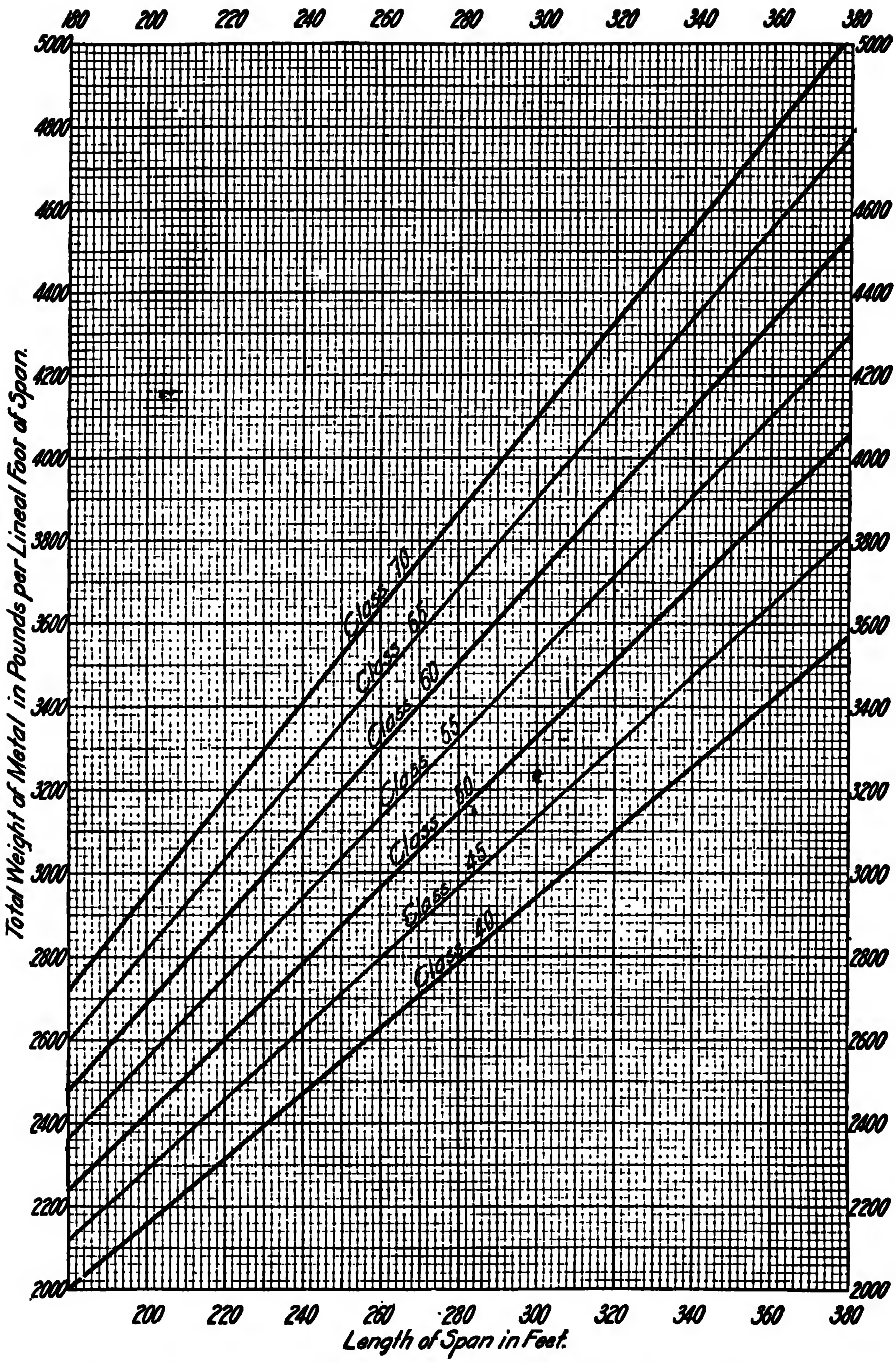


FIG. 55*p*. Single-track-railway, Through, Pin-connected, Pratt-truss Spans—Total Metal in Span.

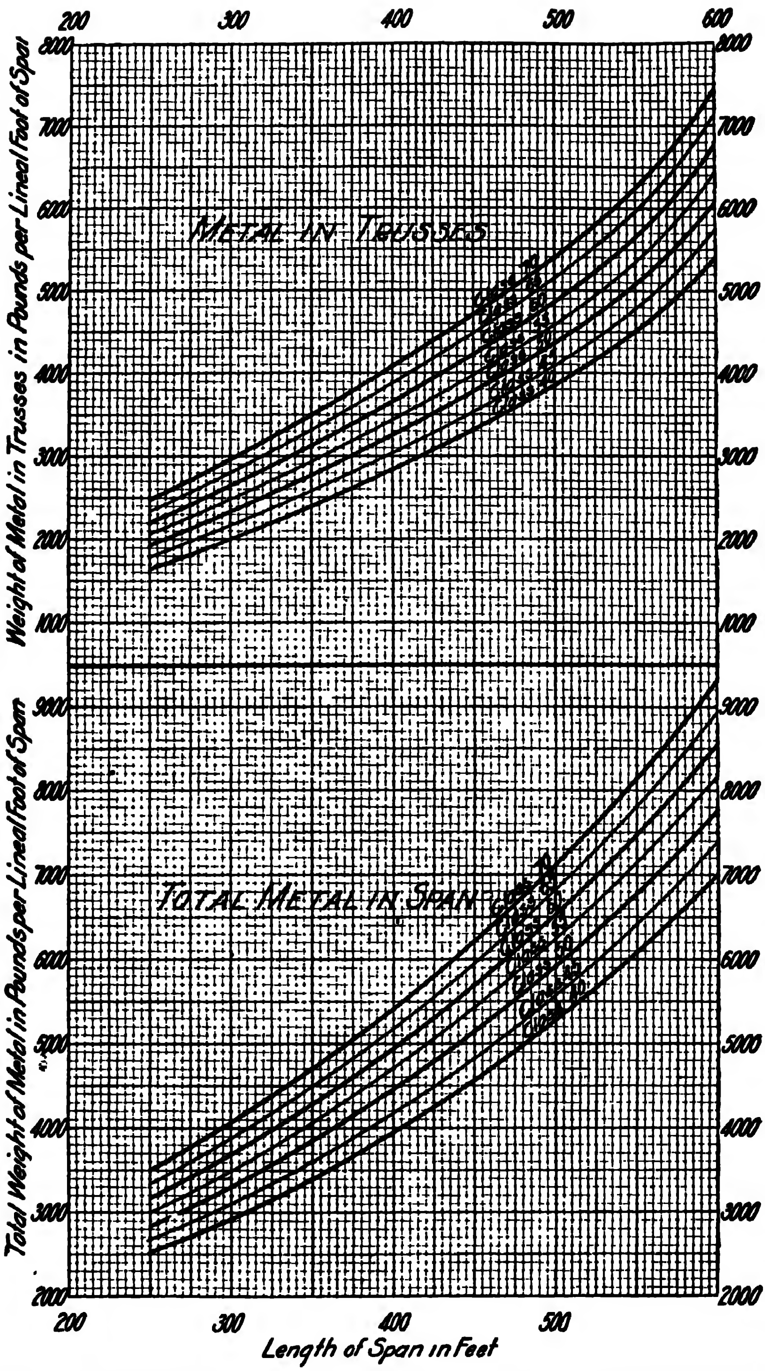


Fig. 55q. Single-track-railway, Through, Pin-connected, Petit-truss Spans—Metal in Trusses and Total Metal in Span.

cent at a length of 500 feet, which is longer than anyone in these days is likely to build a single-track span. Fig. 55u shows the double-track

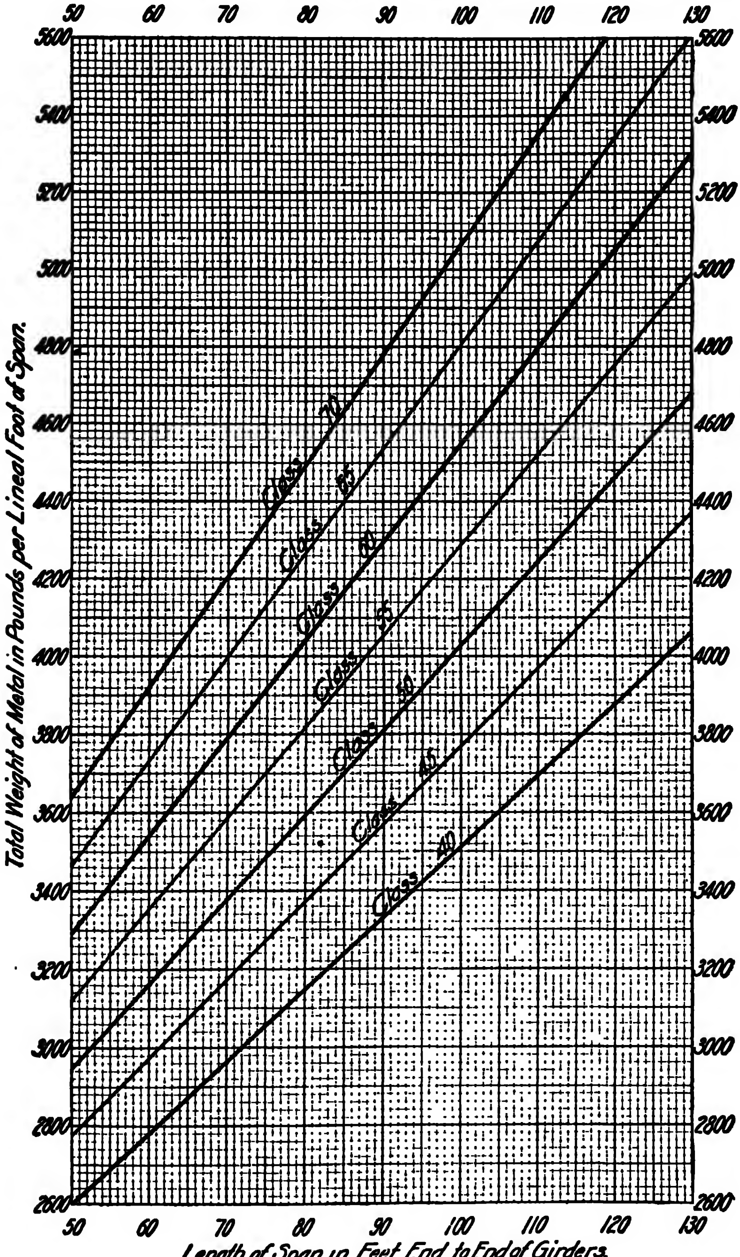


Fig. 55r. Double-track-railway, Half-through, Plate-girder Spans—Total Metal in Span.

percentages to have reached their minima of 31 and 32 at span-lengths of 300 feet or less; and the author would suggest that these be gradually

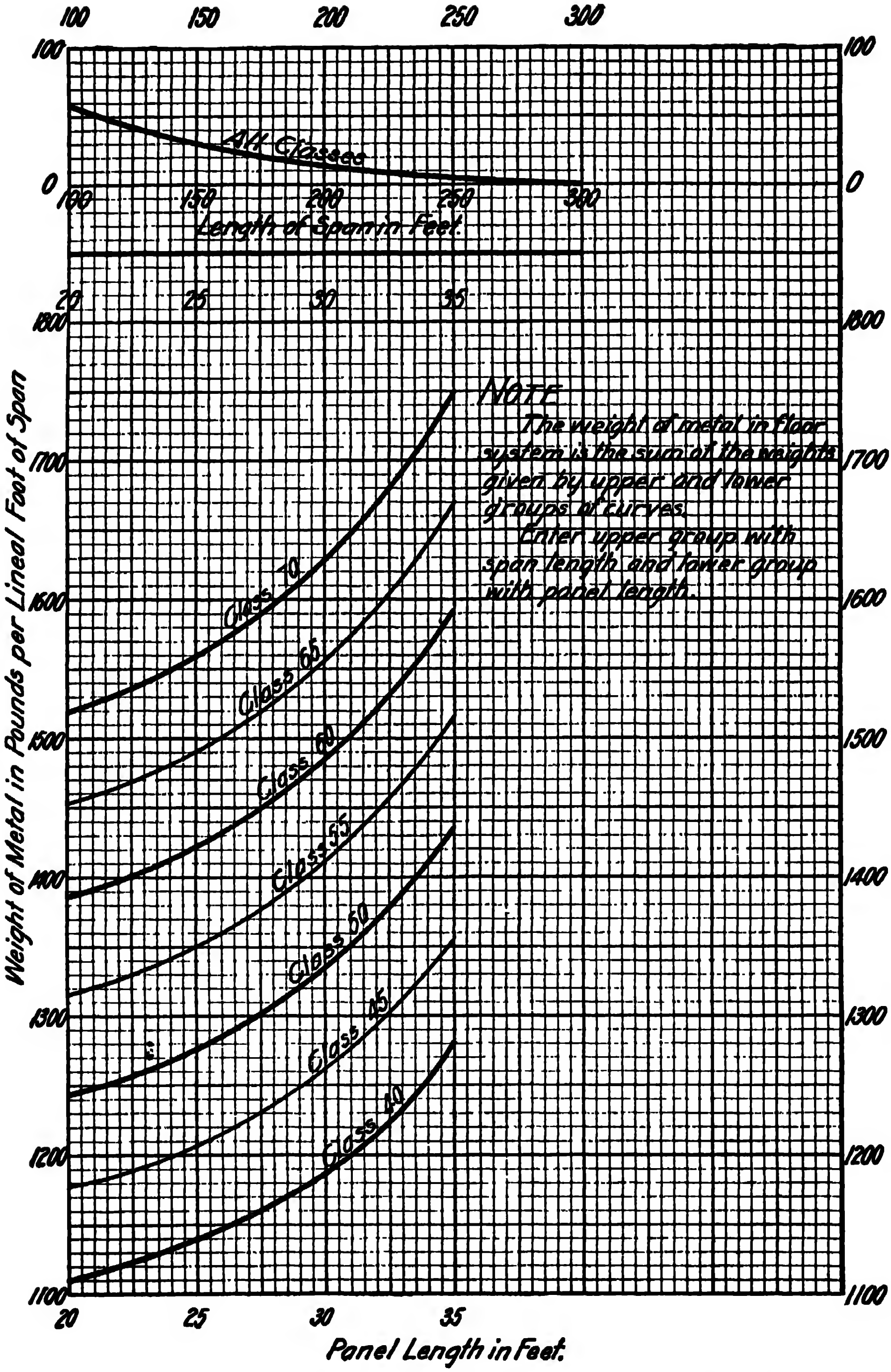


FIG. 55s. Double-track-railway, Through, Riveted, Pratt-truss Spans—Metal in Floor System.

increased to 45 per cent at spans of 800 feet. For heavier loadings than those of double track the curves may be assumed to begin to rise at spans

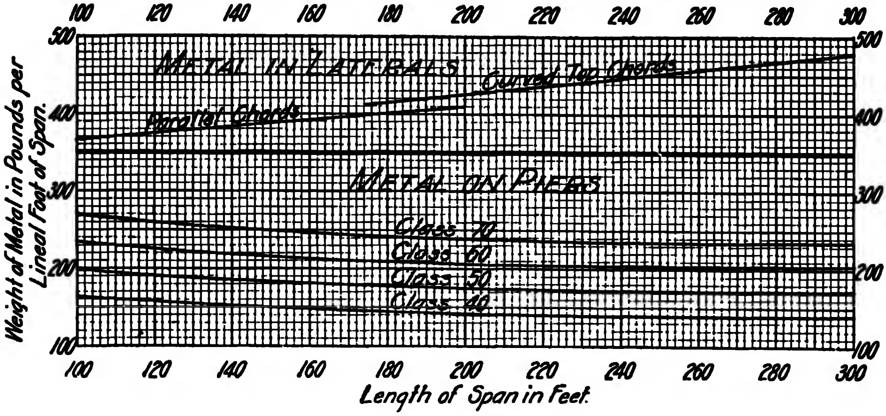
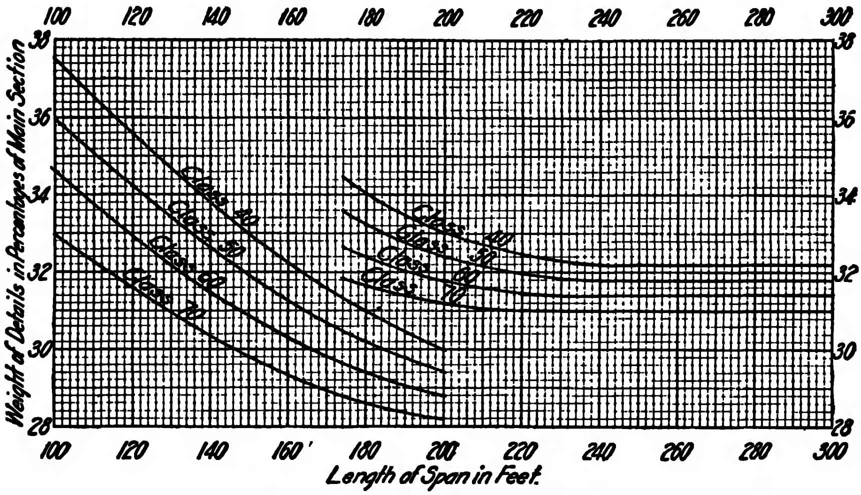


FIG. 55t. Double-track-railway, Through, Riveted, Pratt-truss Spans—Metal in Laterals and on Piers.



NOTE.—Curves on the right are for spans with curved top chords; curves on the left are for spans with parallel chords.

The addition of transverse stiffening diaphragms in all truss members will add about 5 to the percentages shown.

The weights of main sections are to be figured by using the centre to centre lengths, not the actual lengths, of the members. If the actual lengths are used, the percentages given in these curves are to be increased by 2.

FIG. 55u. Double-track-railway, Through, Riveted, Pratt-truss Spans—Percentages of Metal in Truss Details.

of 250 or even 200 feet and to reach 45 per cent at spans of 600 or even 500 feet. Truth to tell, there is almost nothing known positively about

the detail percentages for long, heavy, riveted spans, but the author believes that the figures he has given will prove to be about right. Much depends upon the personal equation and the skill of the detailer. Long-span riveted bridges are just beginning to come into vogue, hence this

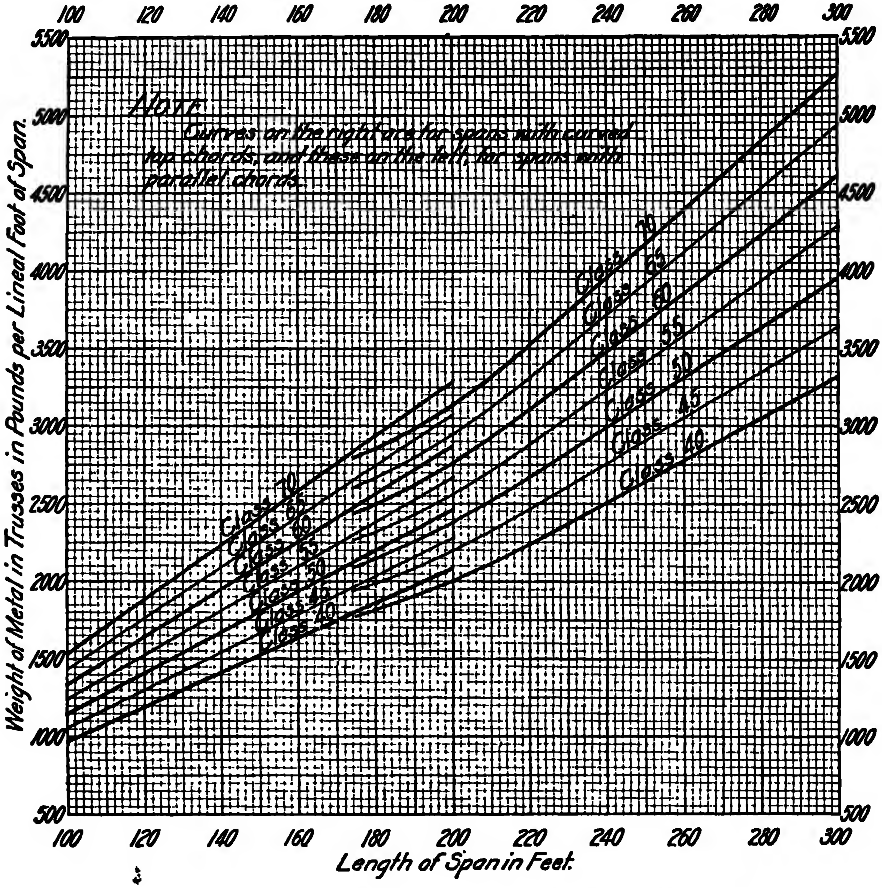


FIG. 55v. Double-track-railway, Through, Riveted, Pratt-truss Spans—Metal in Trusses.

question of percentage to add for details is likely to be an important one. Of course, the assumed percentage cuts no figure in the final design; but by knowing just about what is right, the computer will probably save one or possibly two re-figurings of stresses, sections, and weights of trusses caused by an excess in the resulting dead load.

In the days when he built pin-connected spans the author employed percentages for details varying from 32 for short, light spans down to nearly 20 for long, heavy ones; but in view of the improvements effected in detailing since then, and especially because of the adoption of diaphragms for heavy compression members, he would suggest that the percentages be

35 for spans of 200 feet and 30 for spans of 1,000 feet with proportionate amounts for intermediate spans. In pin-connected trusses there is no such tendency to increase the percentage with the weight per foot of structure (excepting only a trifle by the sudden passing to the use of

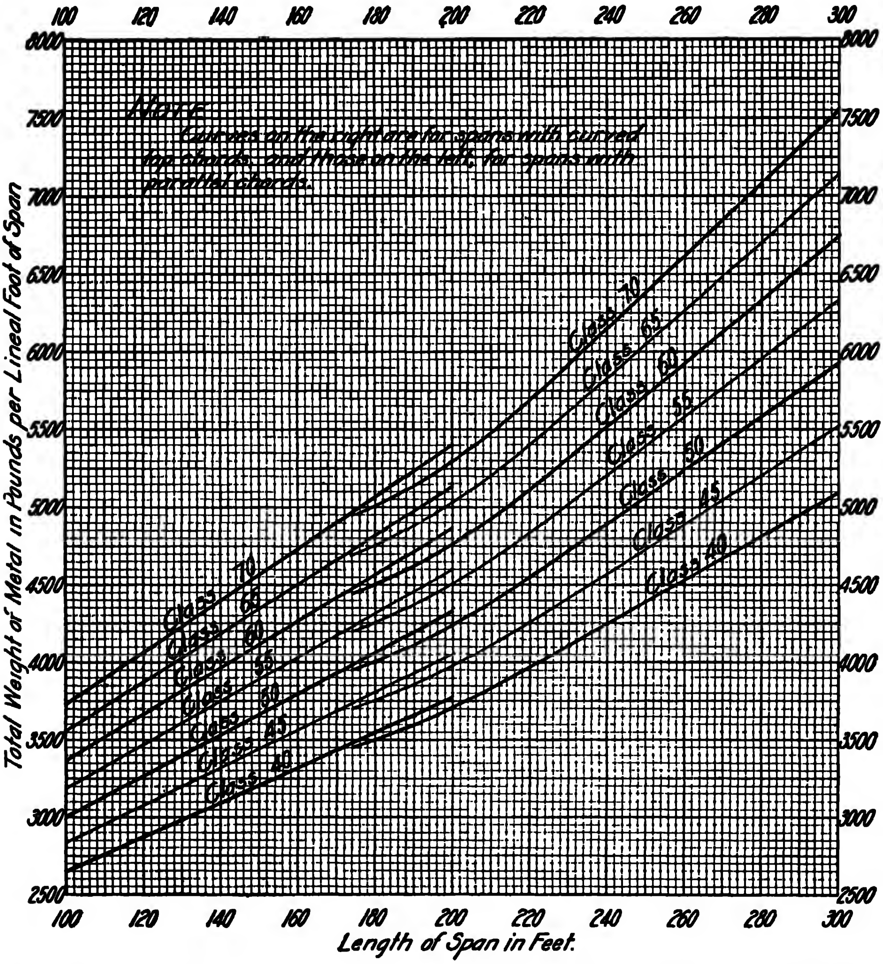


FIG. 55w. Double-track-railway, Through, Riveted, Pratt-truss Spans—Total Metal in Span.

diaphragms in compression members) as there is in riveted structures; but, on the contrary, there is a gradual decrease, mainly because of the greater panel lengths adopted and, therefore, the smaller proportionate number of splices and pins. Again, the percentage depends more upon the span-length than upon the size of the load carried; consequently greater uniformity exists. The author believes that the percentages just given for pin-connected spans are truly reliable and on the safe side, and that,

barring only the effect of the personal equation of the designer, they may be used unhesitatingly.

Swing Spans

In respect to weights of metal for swing spans, although the author has numerous records therefor, he has decided not to reproduce them, because

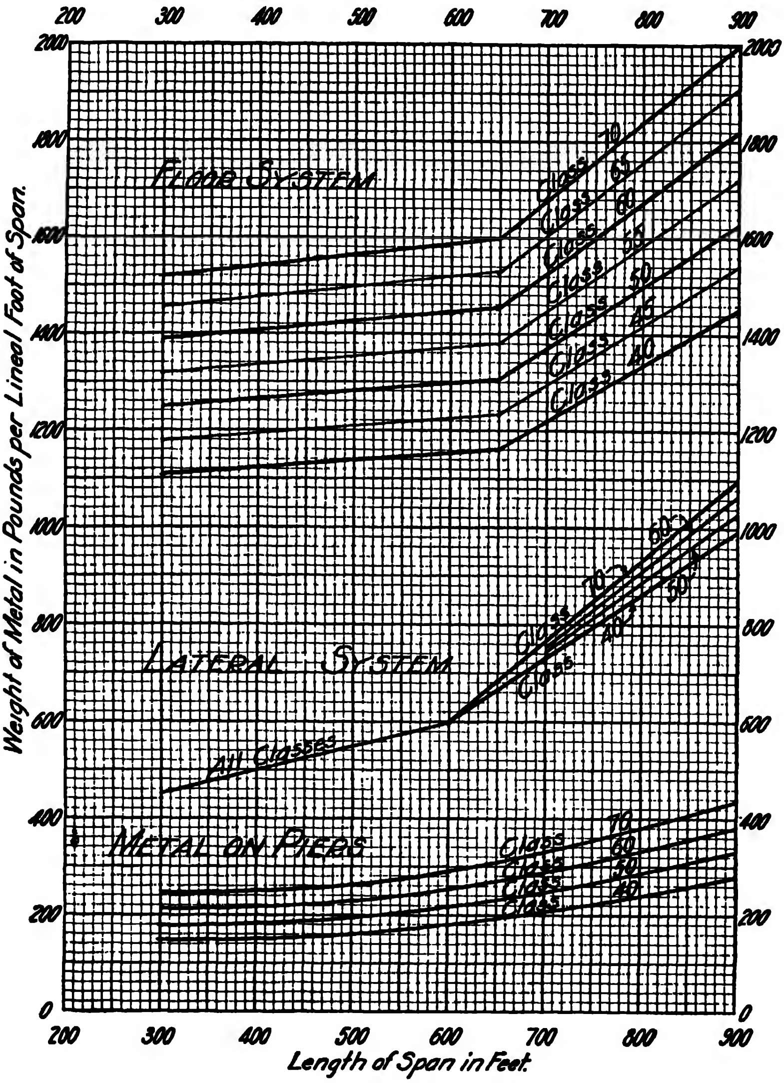


FIG. 55x. Double-track-railway, Through, Riveted, Petit-truss Spans—Metal in Floor System, Laterals, and on Piers.

that type of movable bridge is slowly but surely being supplanted by the vertical lift and the bascule, as pointed out in Chapter XXVIII. However, there are given the following directions for finding the weights of metal

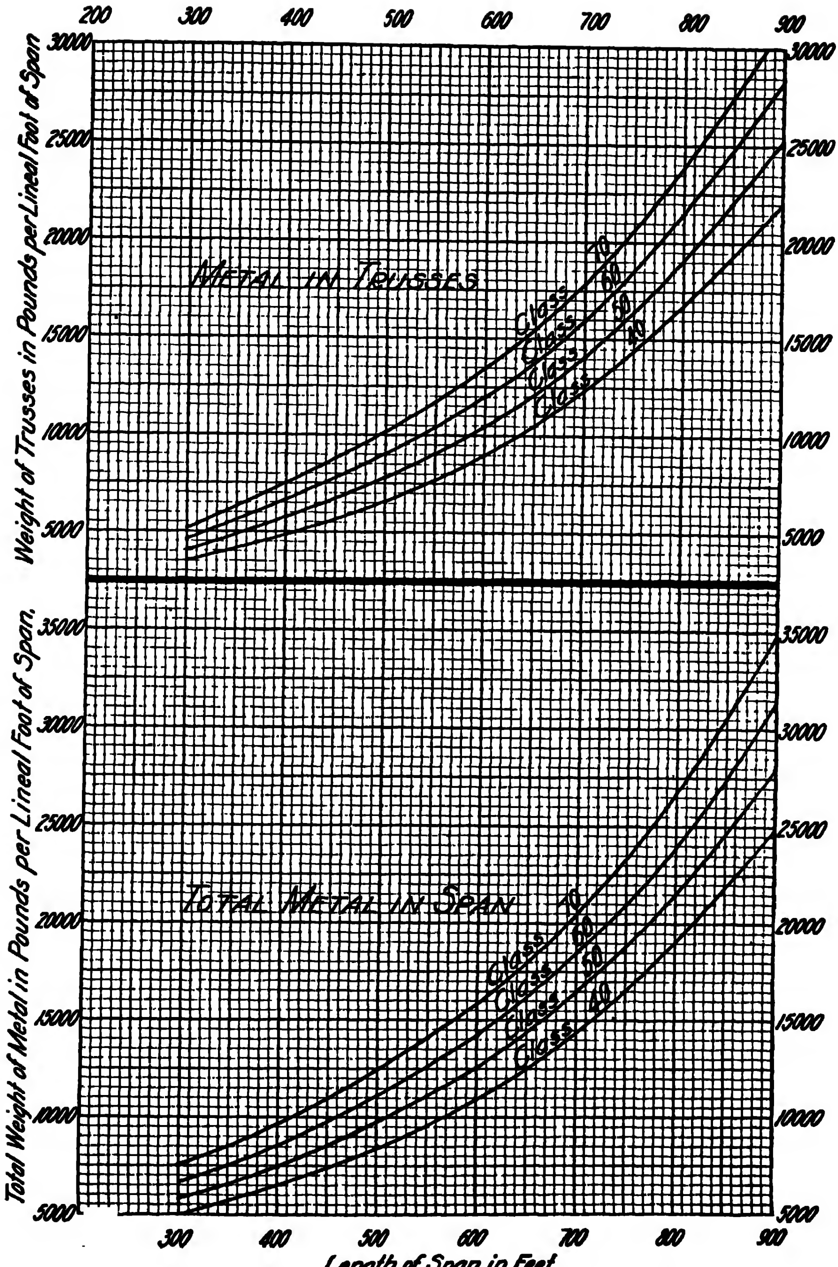


FIG. 55y. Double-track-railway, Through, Riveted, Petit-truss Spans—Metal in Trusses and Total Metal in Span.

for swing spans from the diagrammed weights of metal for fixed spans.

The weight of metal per lineal foot in the floor system is practically the

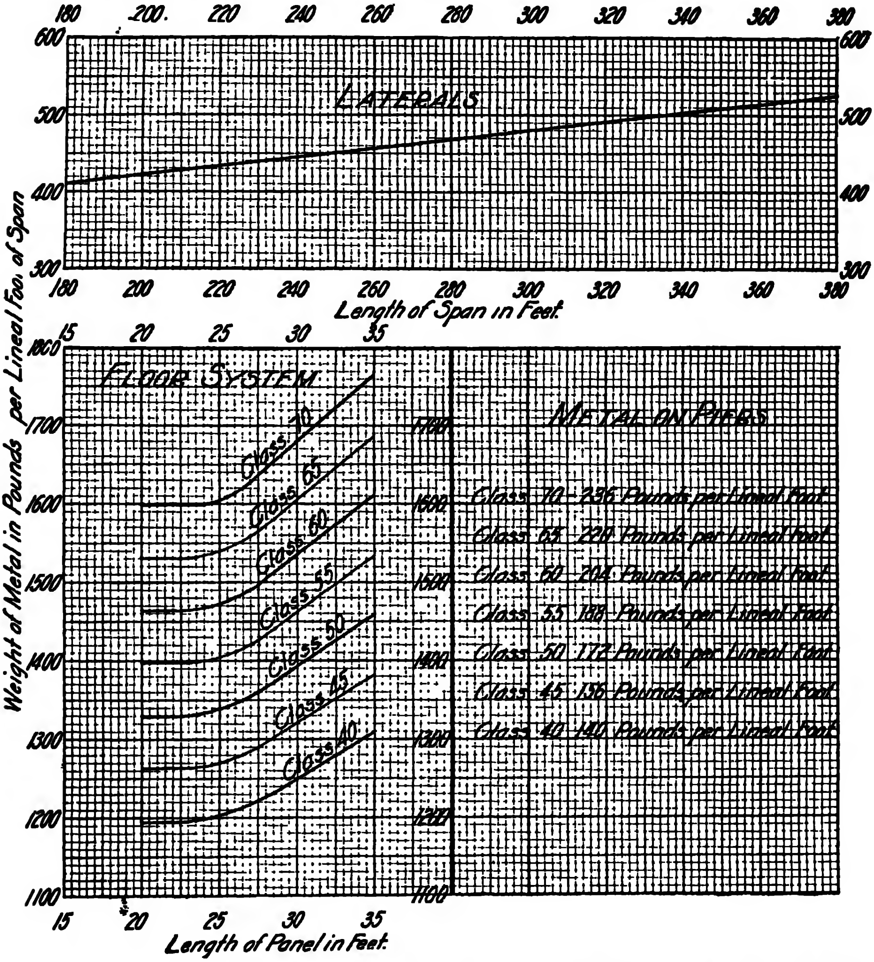


FIG. 55z. Double-track-railway, Through, Pin-connected, Pratt-truss Spans—Metal in Floor System, Laterals, and on Piers.

same as for a fixed span of equal length, provided the perpendicular distance between central planes of trusses is unchanged. For a single-track bridge the weight can be found from Fig. 55e or Fig. 55n by adding to the quantity given by the lower group of curves an amount obtained by entering the upper group with a "span length" of twenty times the perpendicular distance between central planes of trusses.

The weight of metal per lineal foot for the lateral system of a swing span is equal to the corresponding weight for a fixed span having a length equal to seventy (70) per cent of the total length of the said swing span,

provided the distance from centre to centre of trusses is unchanged. In case the width changes, the weight of the lateral system can be assumed to increase or decrease about half as rapidly as does the width.

The weight of metal per lineal foot for the trusses of any swing span can be found by taking that for the corresponding weight of a fixed span

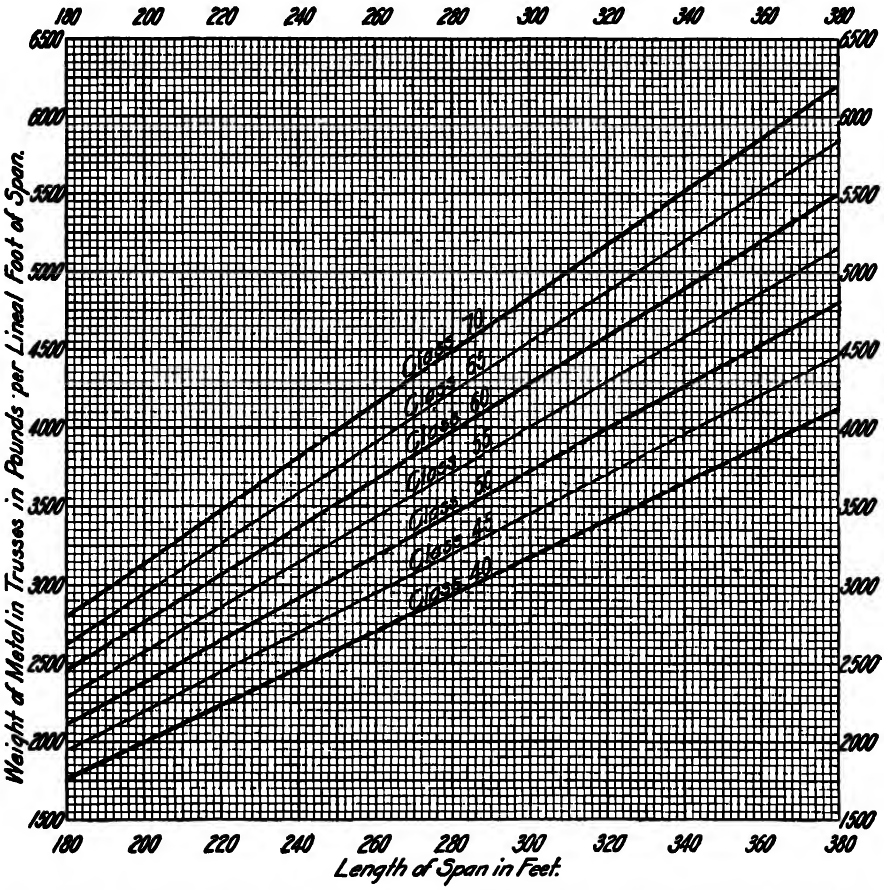


FIG. 55*aa*. Double-track-railway, Through, Pin-Connected, Pratt-truss Spans—Metal in Trusses.

having a length equal to sixty (60) per cent of the total length of the said swing span.

The weight of metal in the drum, machinery (exclusive of motors or engines), and on piers for rim-bearing, single-track railway bridges is just about one-third of the combined weights of the floor system, lateral system, and trusses. For centre bearing swings the amount is somewhat less, but the author has not sufficient data to say exactly what should be the percentage to apply to the aforesaid combined weight in order to find it; but he is of the opinion that it is not less than twenty-five (25) nor more than thirty (30).

Unfortunately, the records for metal weights of double-track railway swing-spans are too meagre to warrant the giving of rules for finding them from the corresponding weights of simple span bridges of the same general type; but from *a priori* reasoning the author ventures the opin-

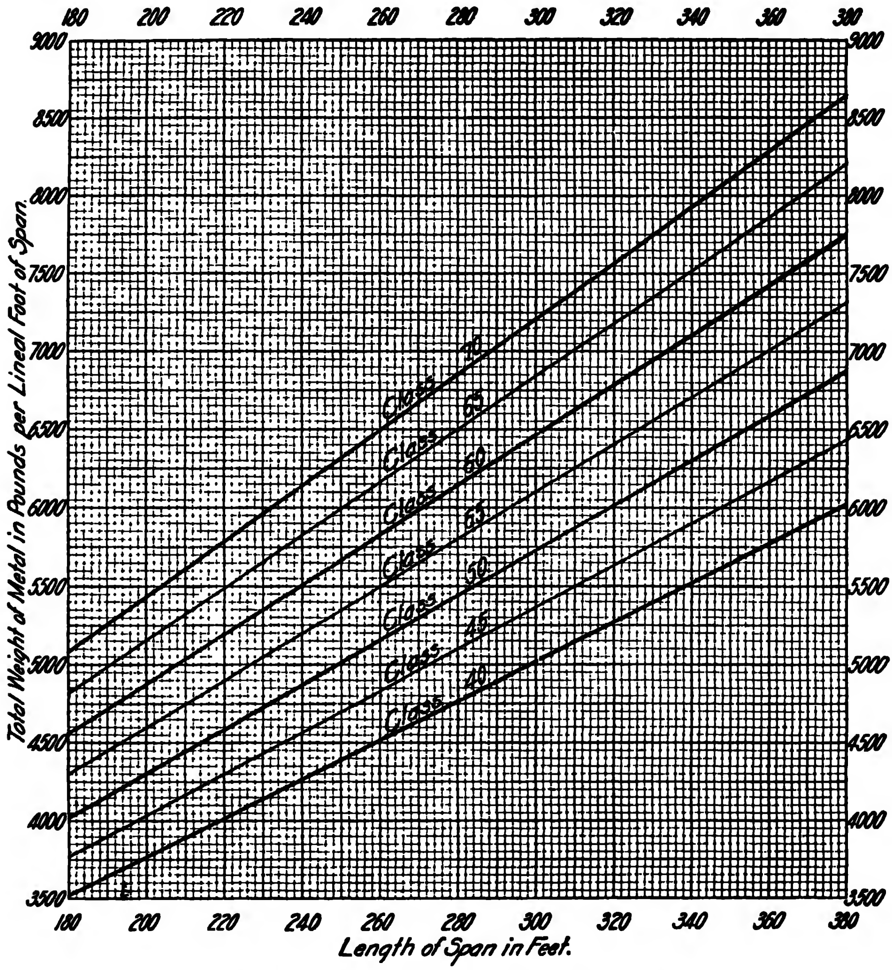


FIG. 55*bb*. Double-track-railway, Through, Pin-connected, Pratt-truss Spans—Total Metal in Span.

ion that the rules previously given for finding the metal weights of single-track swings will apply also to the finding of those for double-track swings, or, at any rate, the error involved by so doing would be quite small. In a comparative design made lately in the author's office for a 480-foot, rim-bearing swing-span for the Pacific Highway Bridge over the Columbia River between Vancouver, Wash., and Portland, Ore., the width of structure being about fifty feet, the percentage for metal in drum, machinery, and on piers was thirty-five and a half, which is probably a little

greater than it would be for a double-track railway bridge of the same span, because the trusses are spaced farther apart.

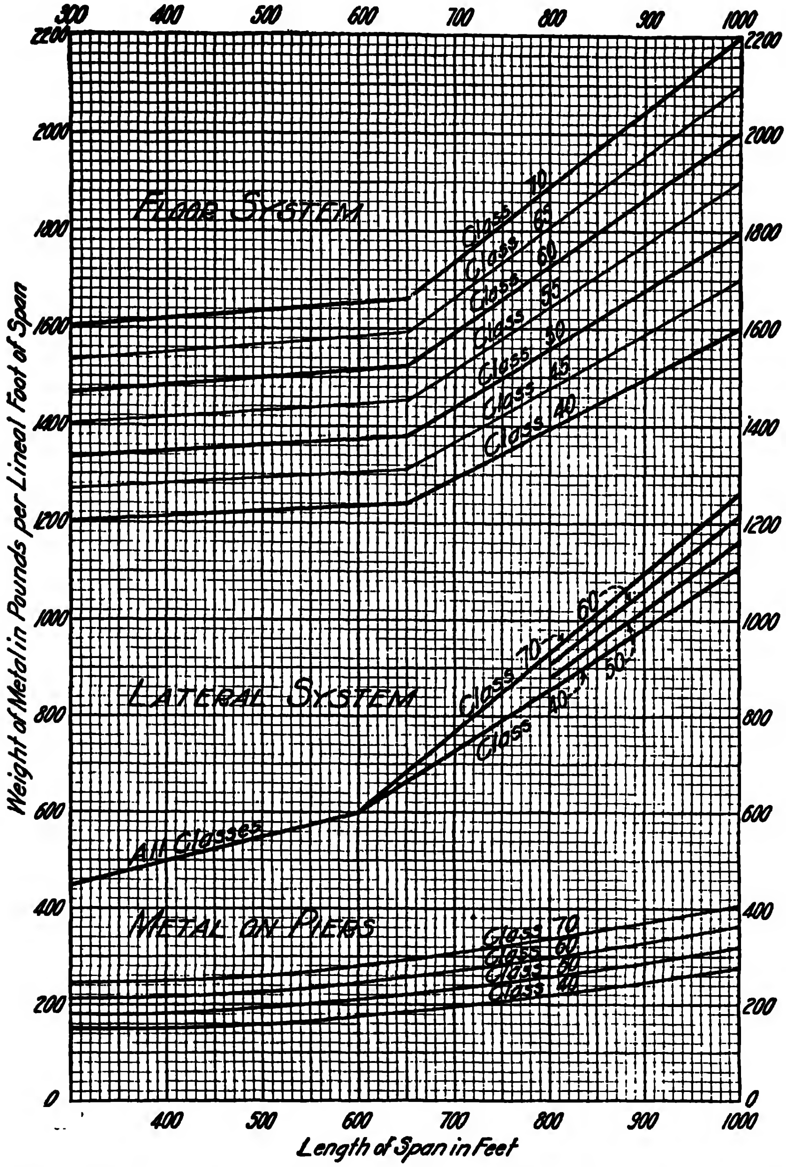


FIG. 55cc. Double-track-railway, Through, Pin-connected, Petit-truss Spans—Metal in Floor System, Laterals, and on Piers.

However, the total weights of metal per lineal foot of span for both single-track and double-track swings (either rim-bearing or centre bearing) can be found from the diagrammed weights of similar fixed-span bridges of the same character and total span-length by ascertaining from

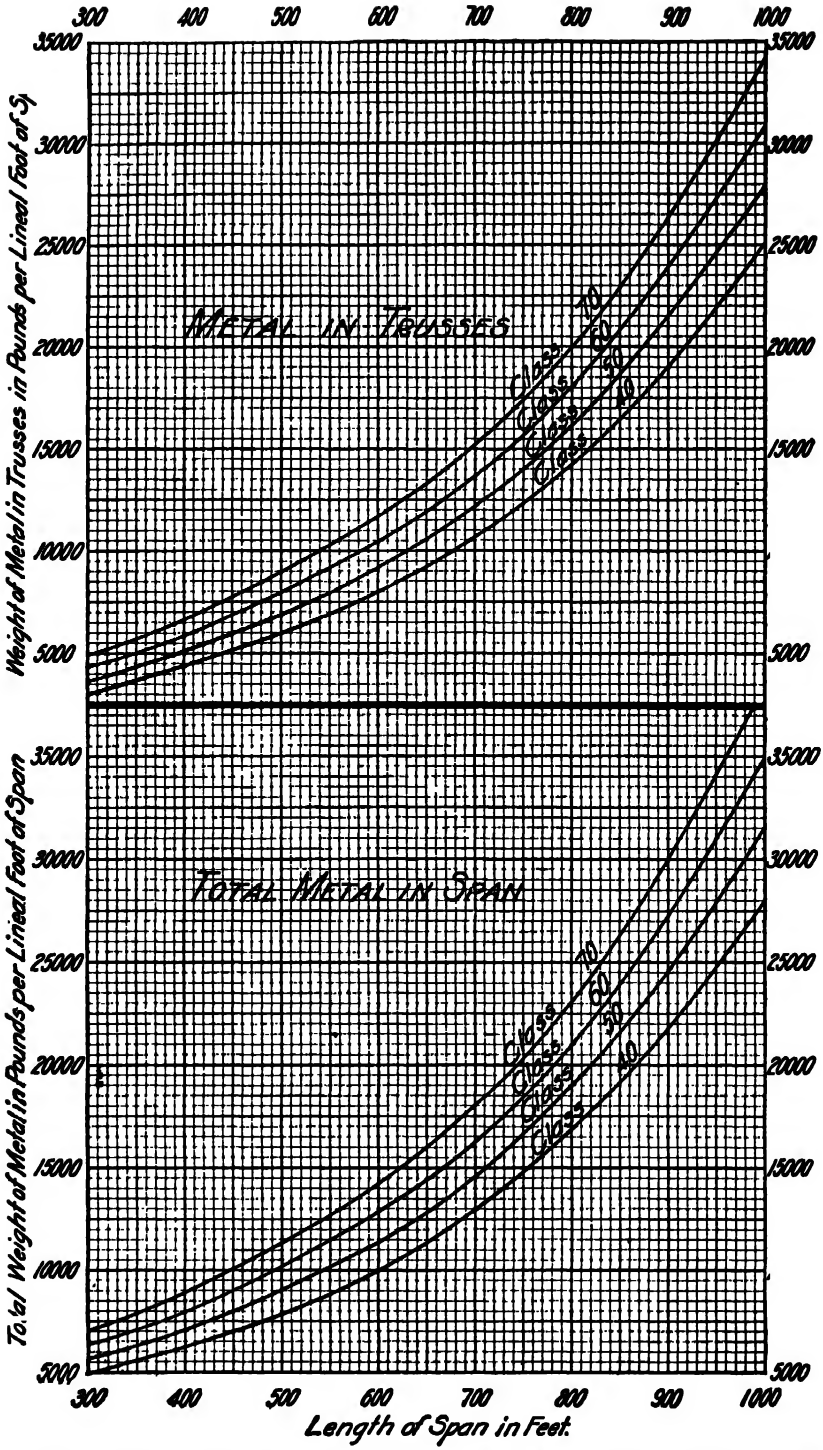


Fig. 55*dd*. Double-track-railway, Through, Pin-connected, Petit-truss Spans—Metal in Trusses and Total Metal in Span.

Fig. 55*ee* the proper percentage to apply to the said weights of metal for simple spans.

SIMPLE GIRDERS AND TRUSSES

In making estimates it is often desirable to know the total weight of metal per lineal foot of span for a girder or truss to carry a certain total load per lineal foot of span, including dead load, live load, and im-

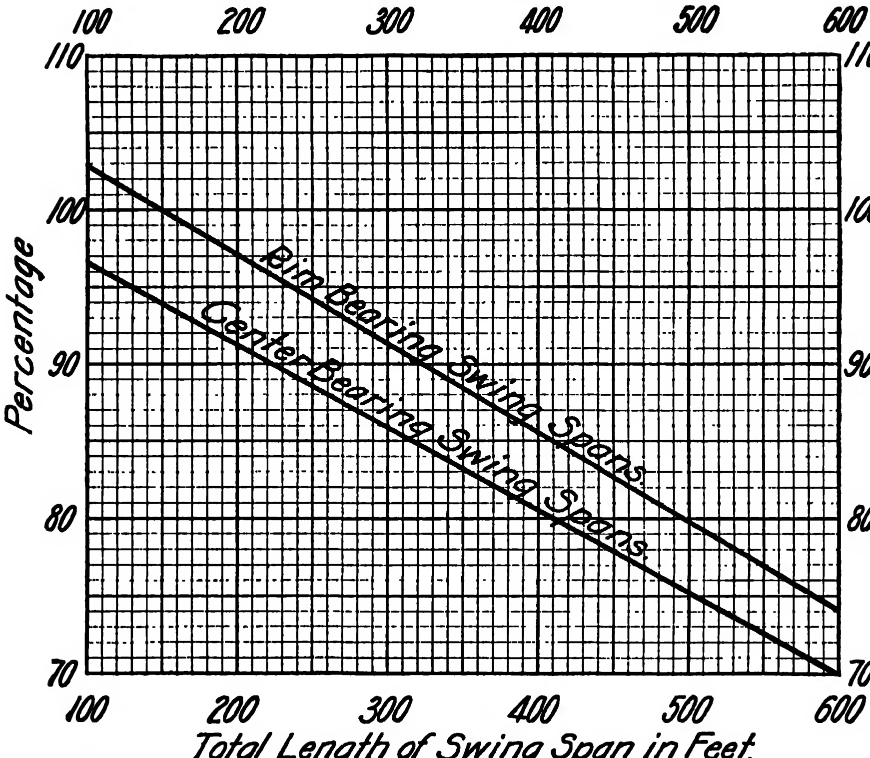
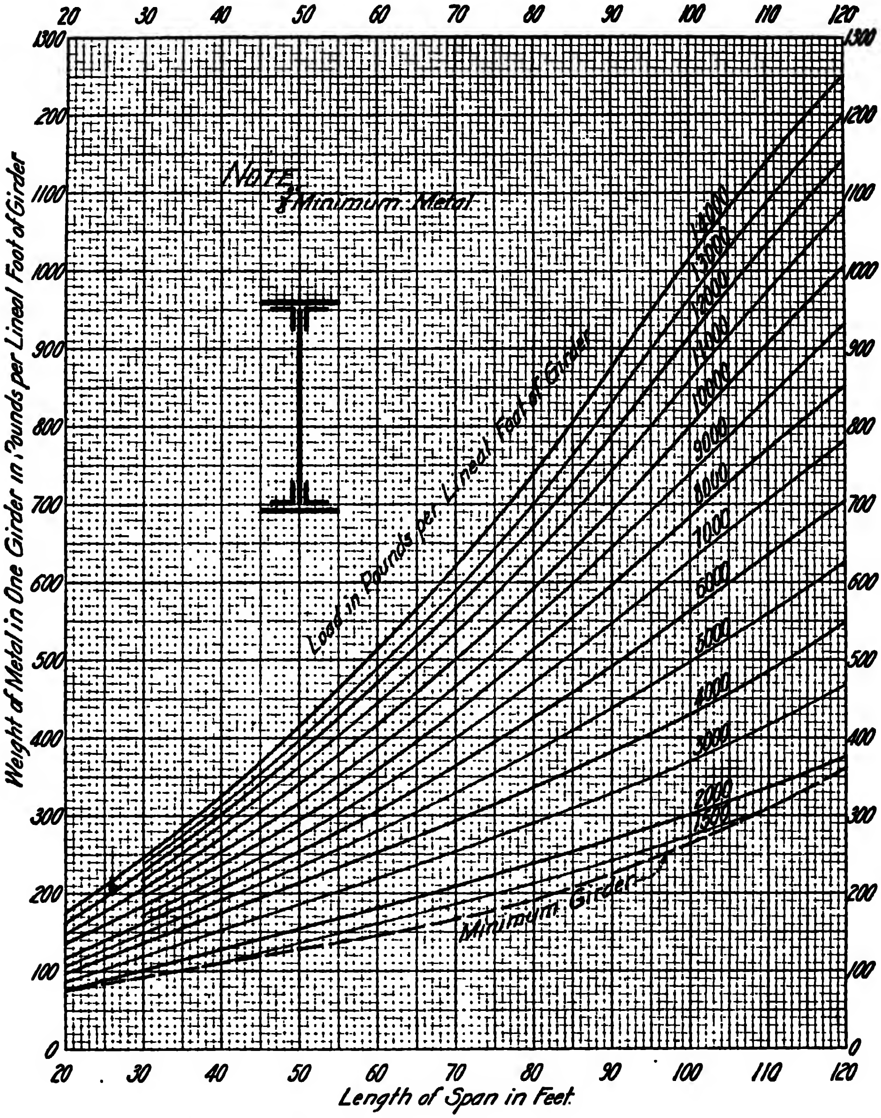


FIG. 55*ee*. Metal in Swing Spans, in Percentages of Weights of Simple Spans of the Same Total Length.

pact. Figs. 55*ff* to 55*ll*, inclusive, give such weights respectively for plate-girders of economic depth; through, riveted Pratt-trusses; through, riveted Petit-trusses; deck, riveted Pratt-trusses; light, riveted, through highway-trusses with minimum thickness of metal equal to five-sixteenths ($\frac{5}{16}$) of an inch; through, pin-connected Pratt-trusses; and through, pin-connected Petit-trusses. These curves are self-explanatory. The load per lineal foot includes the weight of the girder or truss in every instance. The author has been employing diagrams similar to the seven in the last group for some ten years, and has found them exceedingly useful and very accurate, notwithstanding the predictions of his assistant engineers to whom he allotted the task of their preparation; for without

exception they declared that correct diagramming on the indicated lines was impossible.

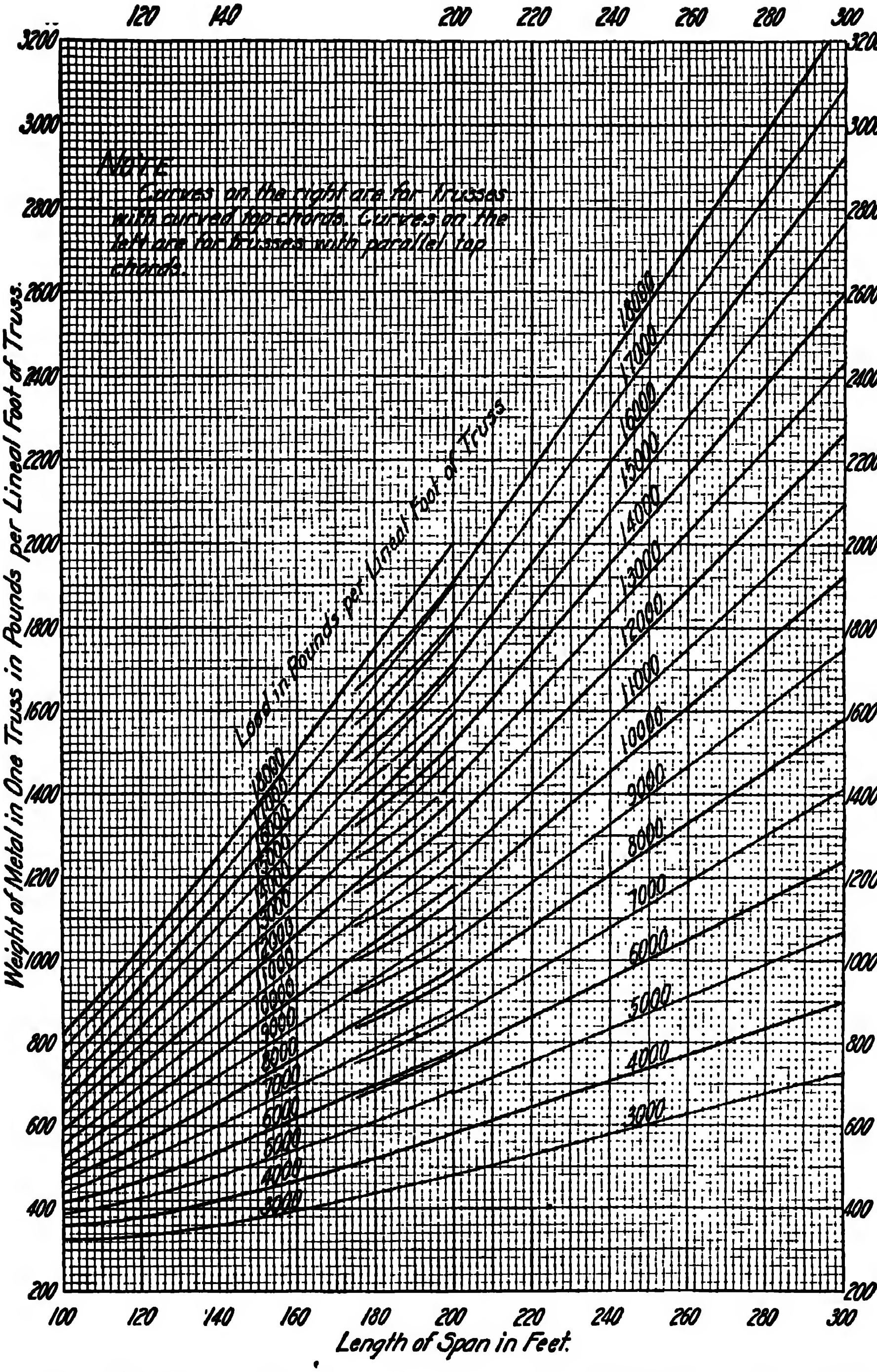
Fig. 55*mm* gives the weights of pedestals at ends of truss spans for



NOTE.—The weight of the girder is to be included in finding the load on the girder.

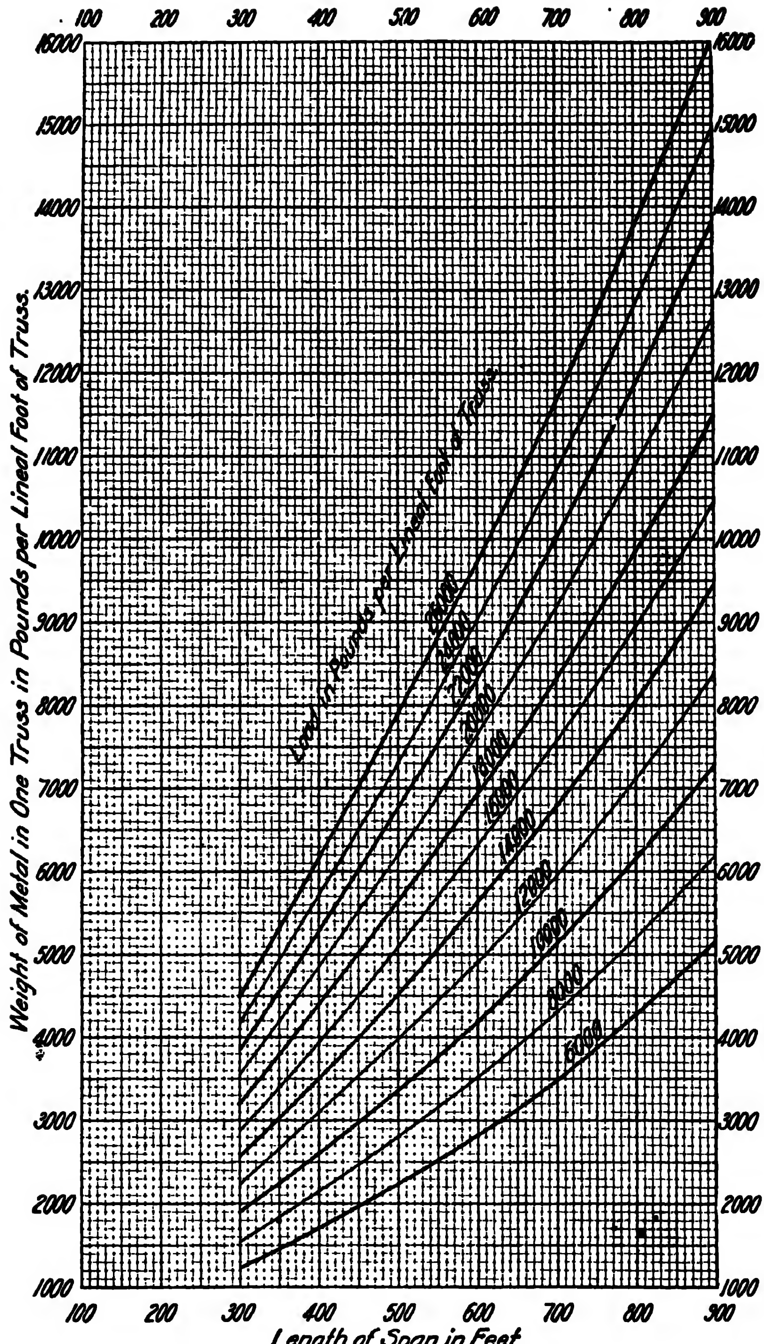
FIG. 55*ff*. Plate Girders with Riveted End-connections—Metal in One Girder.

total loads at corners, varying from small amounts up to 2,500,000 lbs. per corner. All shoes are of cast steel; and the weights include those of the pedestal pins and nuts.



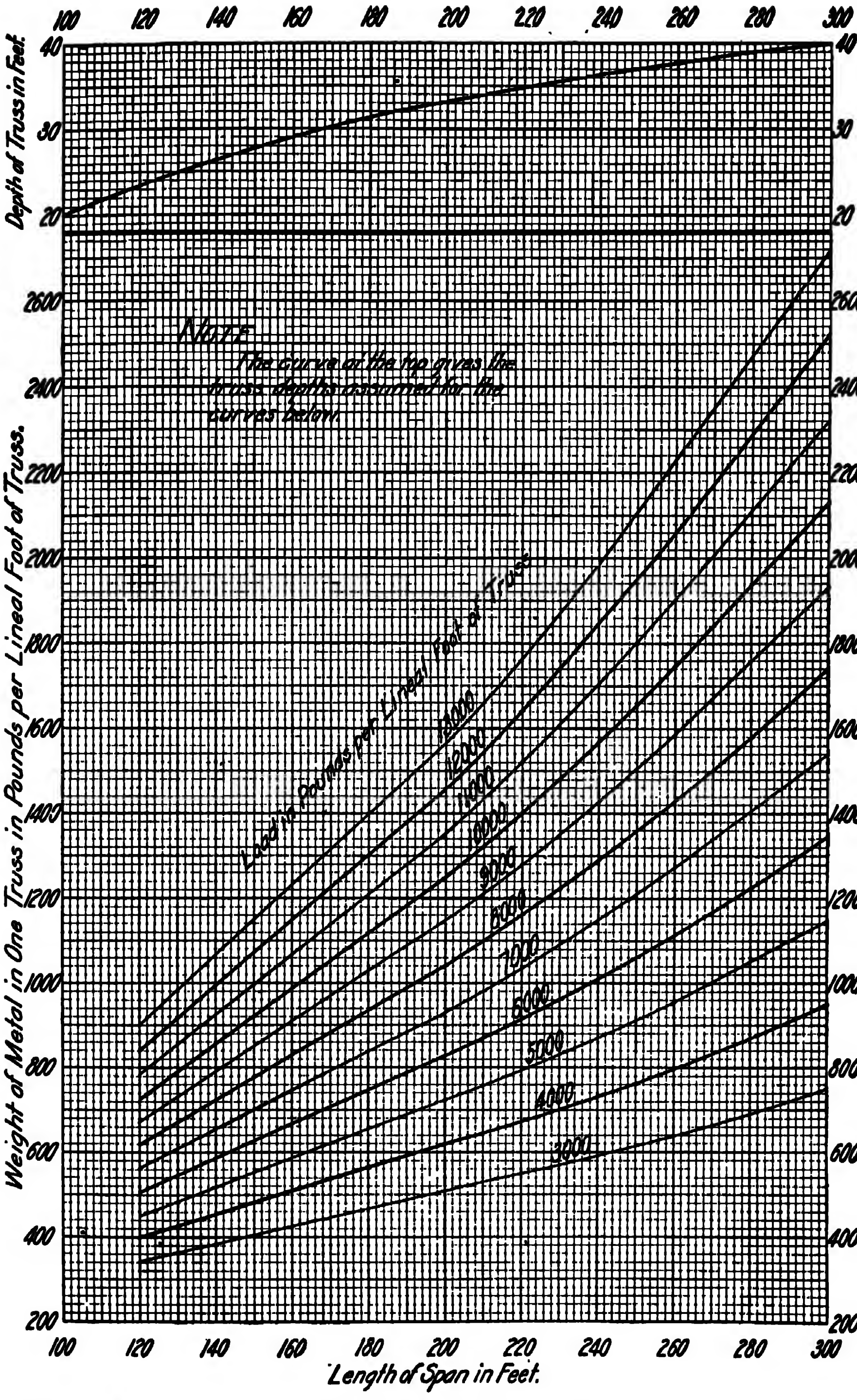
NOTE.—The weight of the truss is to be included in finding the load on the truss.

FIG. 55*gg*. Through, Riveted Pratt Trusses—Metal in One Truss.



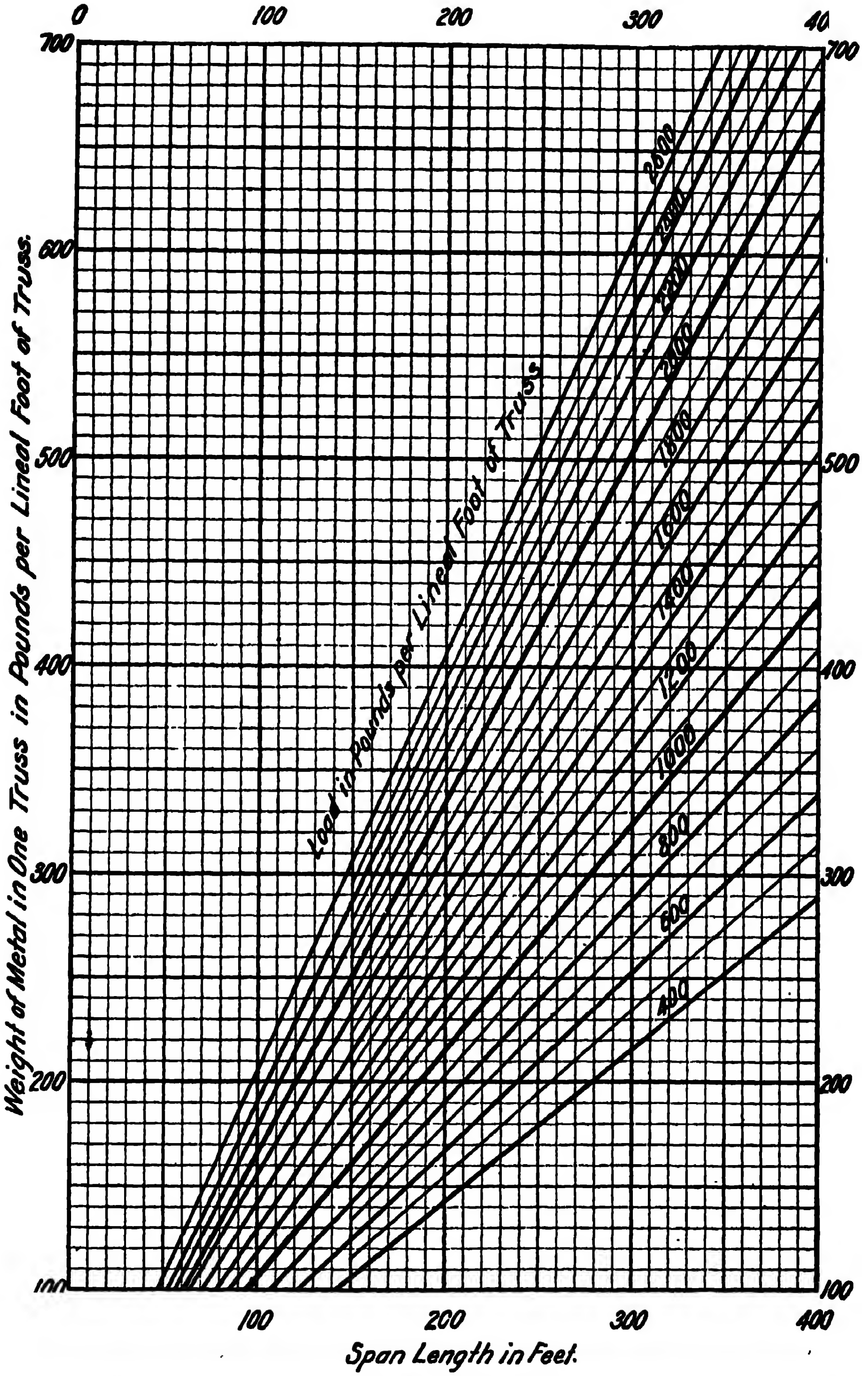
NOTE.—The weight of the truss is to be included in finding the load on the truss.

FIG. 55*hh*. Through, Riveted Petit Trusses—Metal in One Truss.



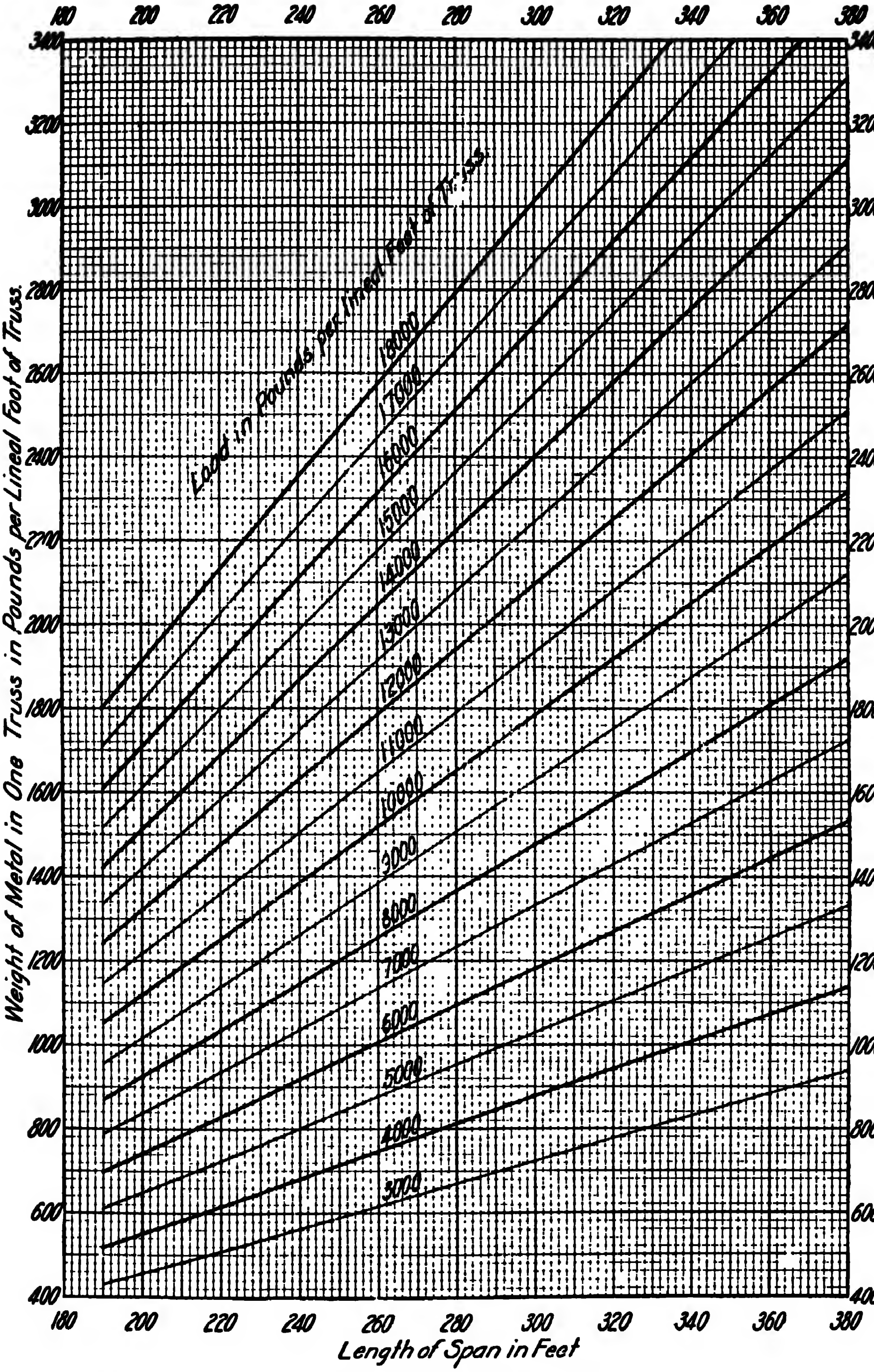
NOTE.—The weight of the truss is to be included in finding the load on the truss.

FIG. 55*ii*. Deck, Riveted Pratt Trusses—Metal in One Truss.



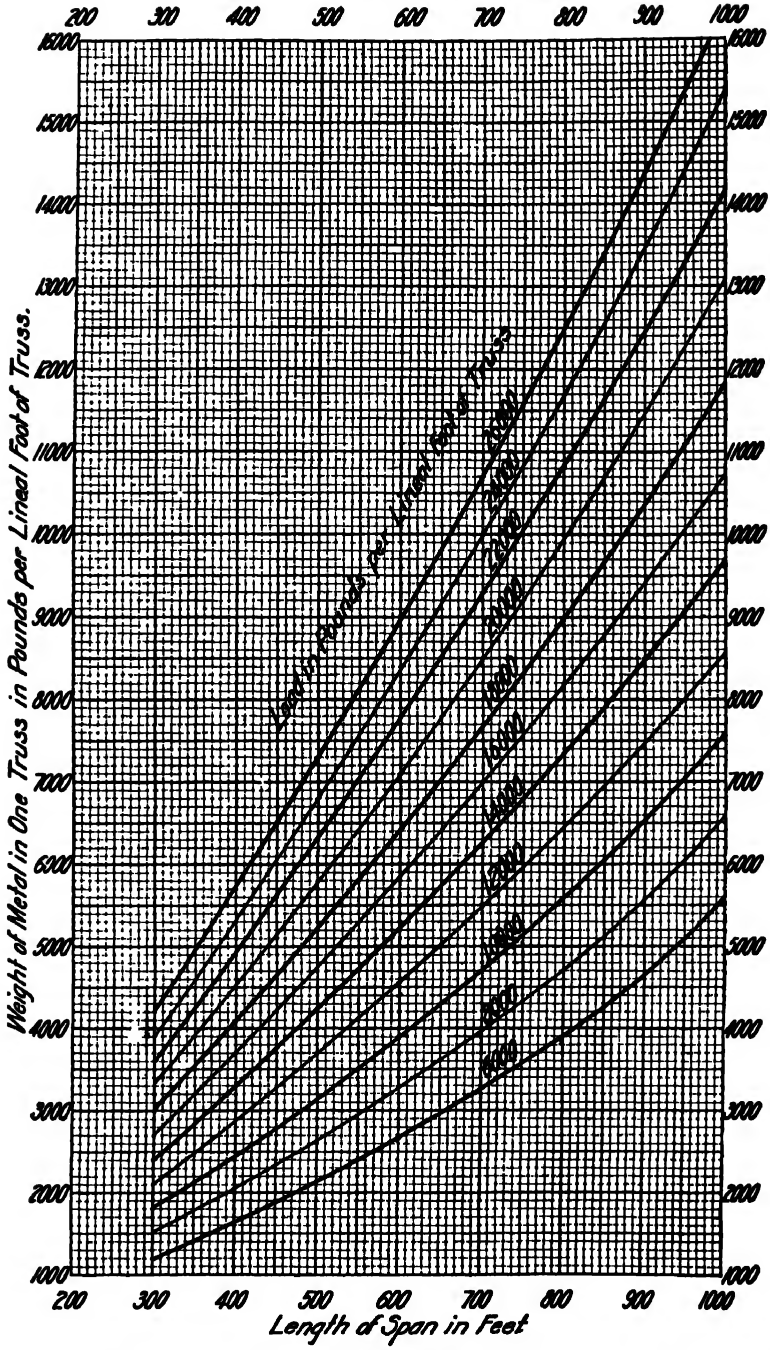
Note.—The weight of the truss is to be included in finding the load on the truss.

Fi(Light, Through, Riveted, Highway Trusses—Metal in One Truss.



NOTE.—The weight of the truss is to be included in finding the load on the truss.

FIG. 55*kk*. Through Pin-connected Pratt Trusses—Metal in One Truss.



Note.—The weight of the truss is to be included in finding the load on the truss.

Fig. 55*ll*. Through, Pin-connected Petit Trusses—Metal in One Truss.

Single-Track Railway Trestles—Type I

Figs. 55*nn* to 55*rr*, inclusive, show weights of metal for single-track, steam-railway, steel trestles with every alternate span a tower span, up to a limit of two hundred and forty (240) feet in height, measuring from top of masonry to base of rail.

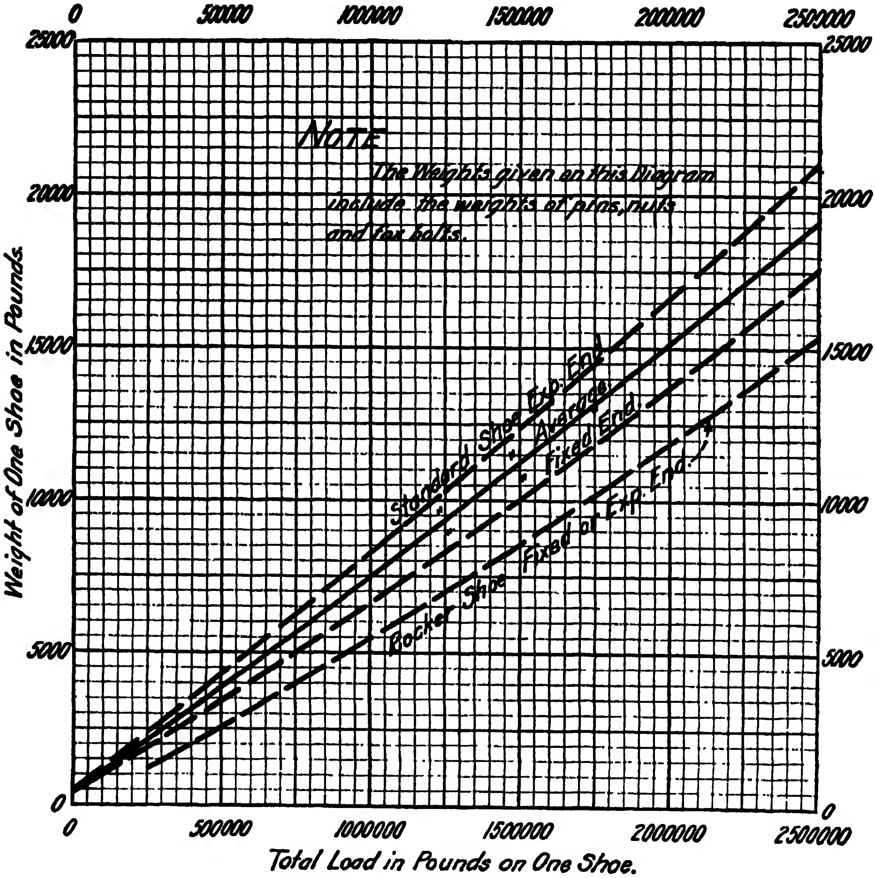


Fig. 55*mm*. Metal on Piers for Truss Spans.

Fig. 55*nn* gives the weights of metal per lineal foot of structure for the girders and girder bracing. (It is to be noted that there are no cover plates for the top flanges. They are omitted so as to avoid notching the ties to fit rivet heads.)

Fig. 55*oo* gives, for various heights from top of masonry to base of rail, the lengths of tower spans and of intermediate spans, and the distances from centre to centre of towers, the employment of which will make the weight of metal in the structure a minimum.

Fig. 55*pp* gives weight of metal for both the longitudinal and the

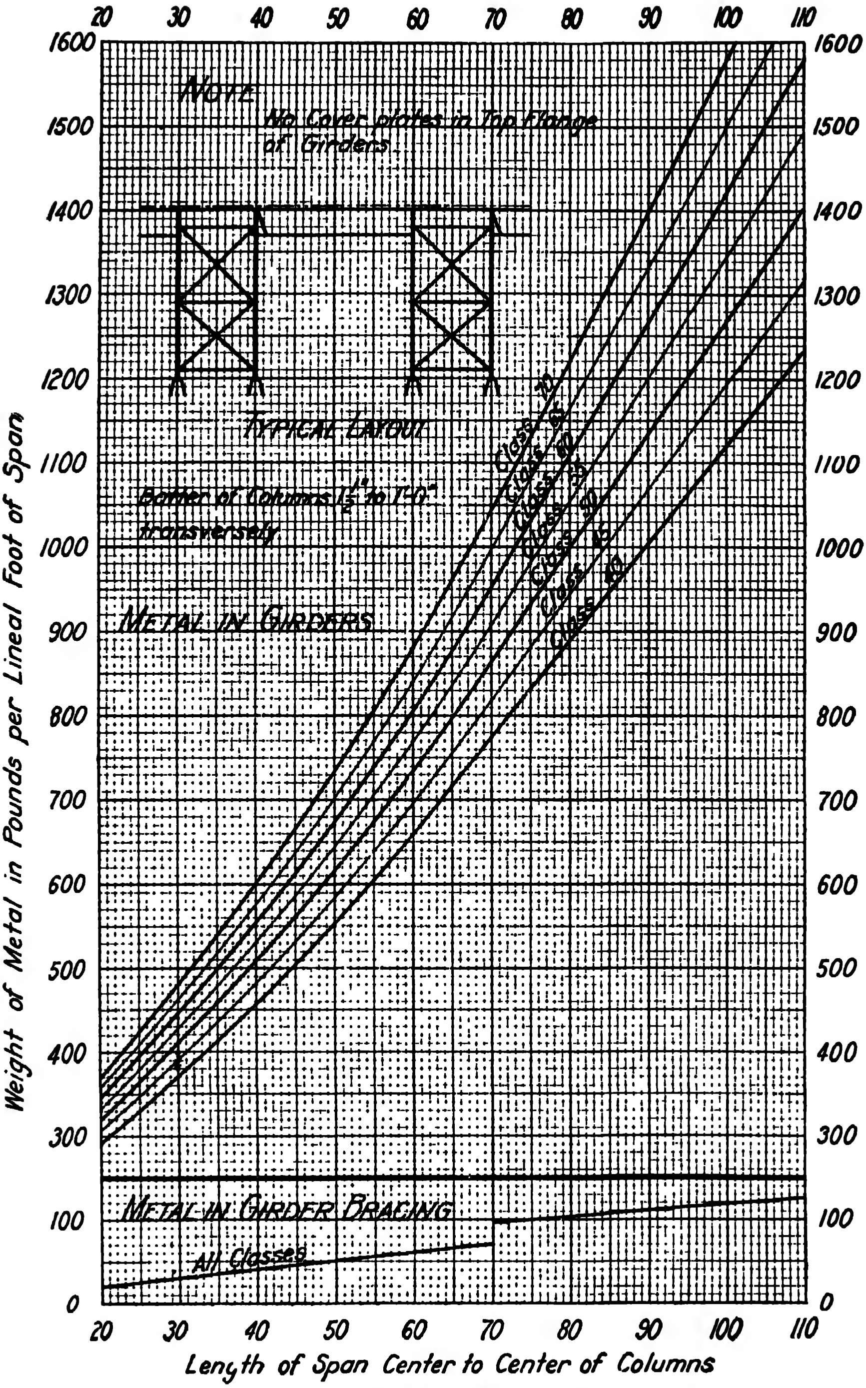


FIG. 55*nn*. Single-track-railway Trestles, Type I—Metal in Girders and Girder Bracing.

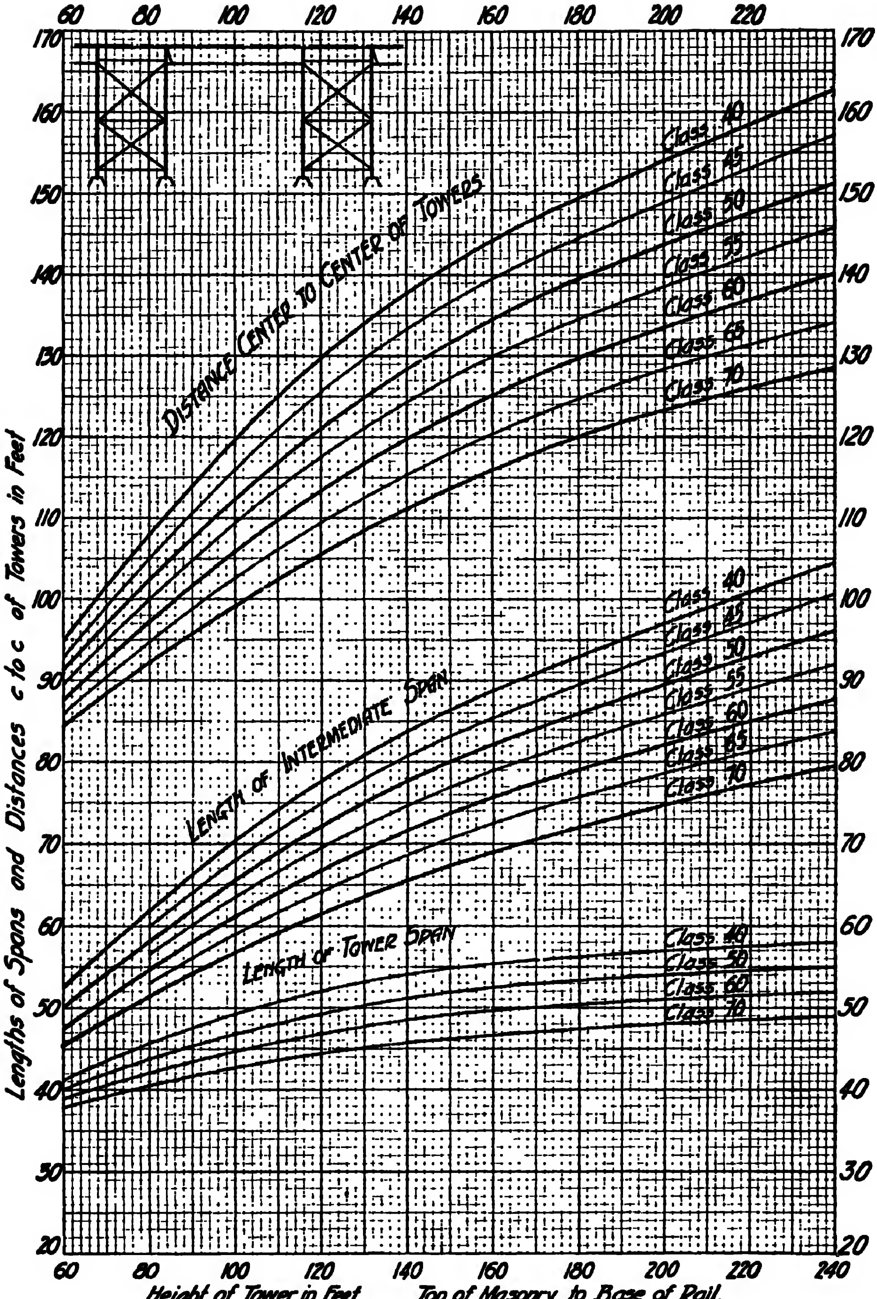


Fig. 55oo. Single-track-railway Trestles, Type I—Economic Span Lengths.

transverse bracing of the towers. The curves of the former are adjusted for various lengths of tower spans, and those of the latter for two standard batters of columns.

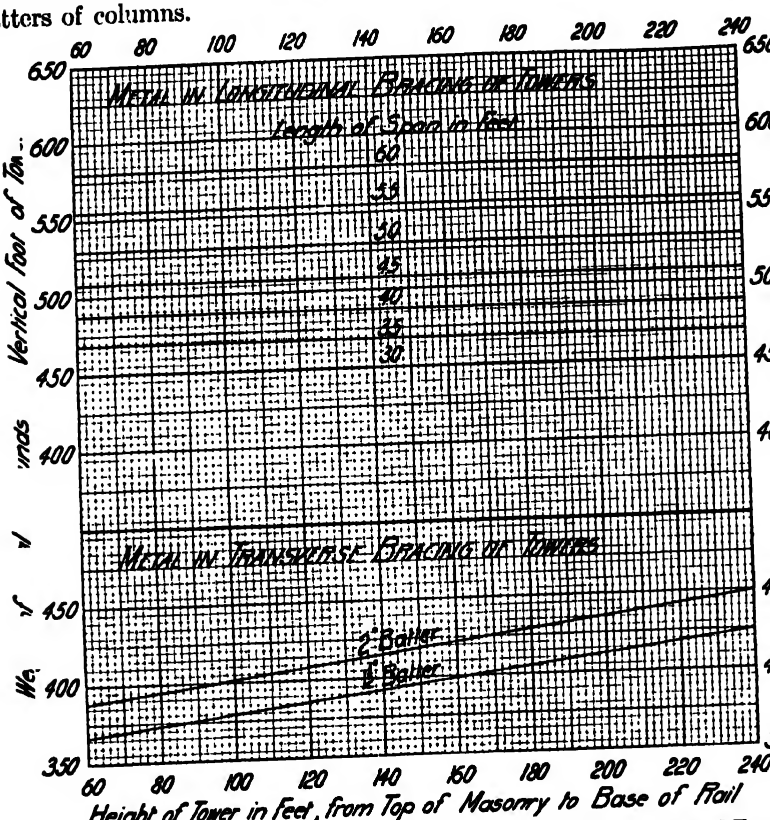


FIG. 55*pp*. Single-track Railway Trestles, Type I—Metal in Longitudinal and Transverse Bracing of Towers.

Fig. 55*qq* indicates the weights of metal in the four columns of any tower. This is a "double tracing" diagram similar to Fig. 55*j*.

Fig. 55*rr* shows, for various heights of trestle, the minimum total weight of metal per lineal foot of structure.

Fig. 55*ss* gives the approximate maximum loads on the pedestals of trestles of this type. It also is a "double tracing" diagram.

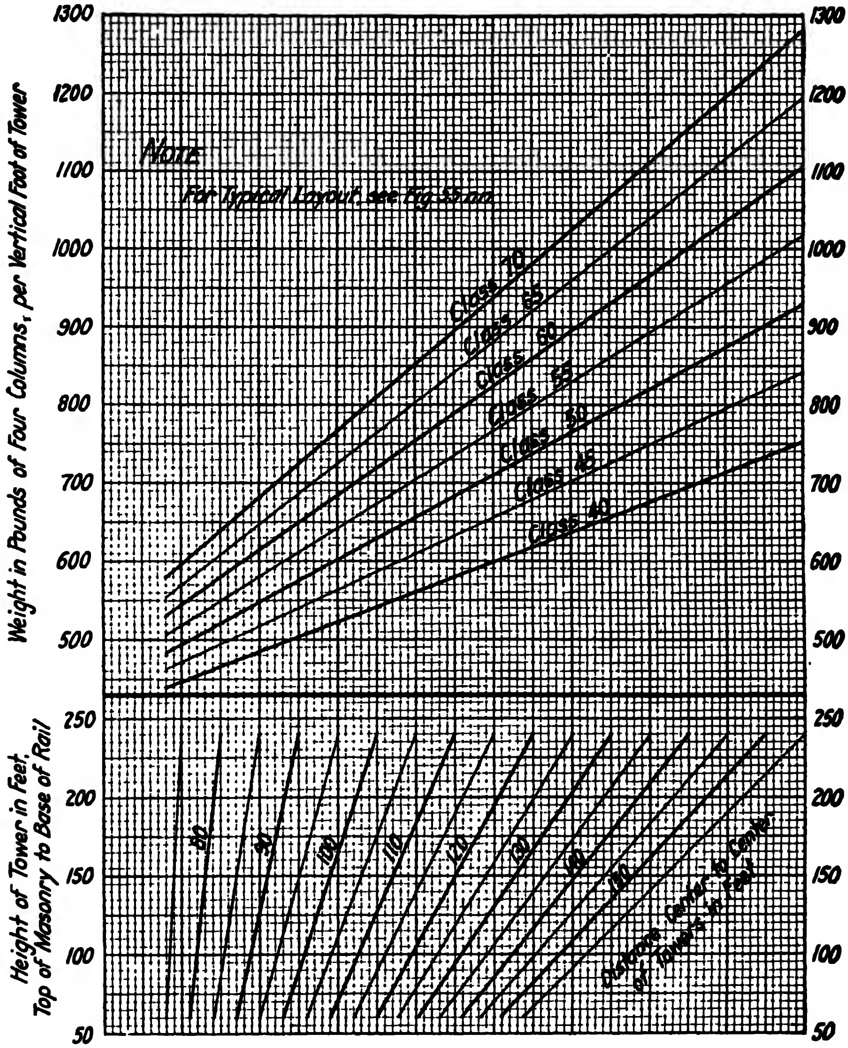
The above diagrams were figured upon the assumption that the structures were on tangent. For trestles on curves, the weights given thereon are to be increased two per cent for each degree of curvature.

SINGLE-TRACK RAILWAY TRESTLES—TYPE II

Figs. 55*tt* to 55*zz*, inclusive, give weights of metal for single-track railway trestles for an assumed typical layout in which all the towers

are thirty (30) feet long, and in which there are two solitary bents between each pair of adjacent towers.

Fig. 55*tt* shows the average weight of metal in girders and girder bracing per lineal foot of structure.



NOTE.—Enter lower portion of diagram with height of tower and the distance centre to centre of towers, and trace vertically upward to the curve for the live load.

FIG. 55*qq*. Single-track Railway Trestles, Type 1—Metal in Columns of Towers.

Fig. 55*uu* indicates the weights of metal per vertical foot in one bent; and Fig. 55*vv* gives the weights of metal per vertical foot in one tower. Both of these figures are "double tracing" diagrams.

Figs. 55*ww*, 55*xx*, and 55*yy* indicate, for various lengths of interme-

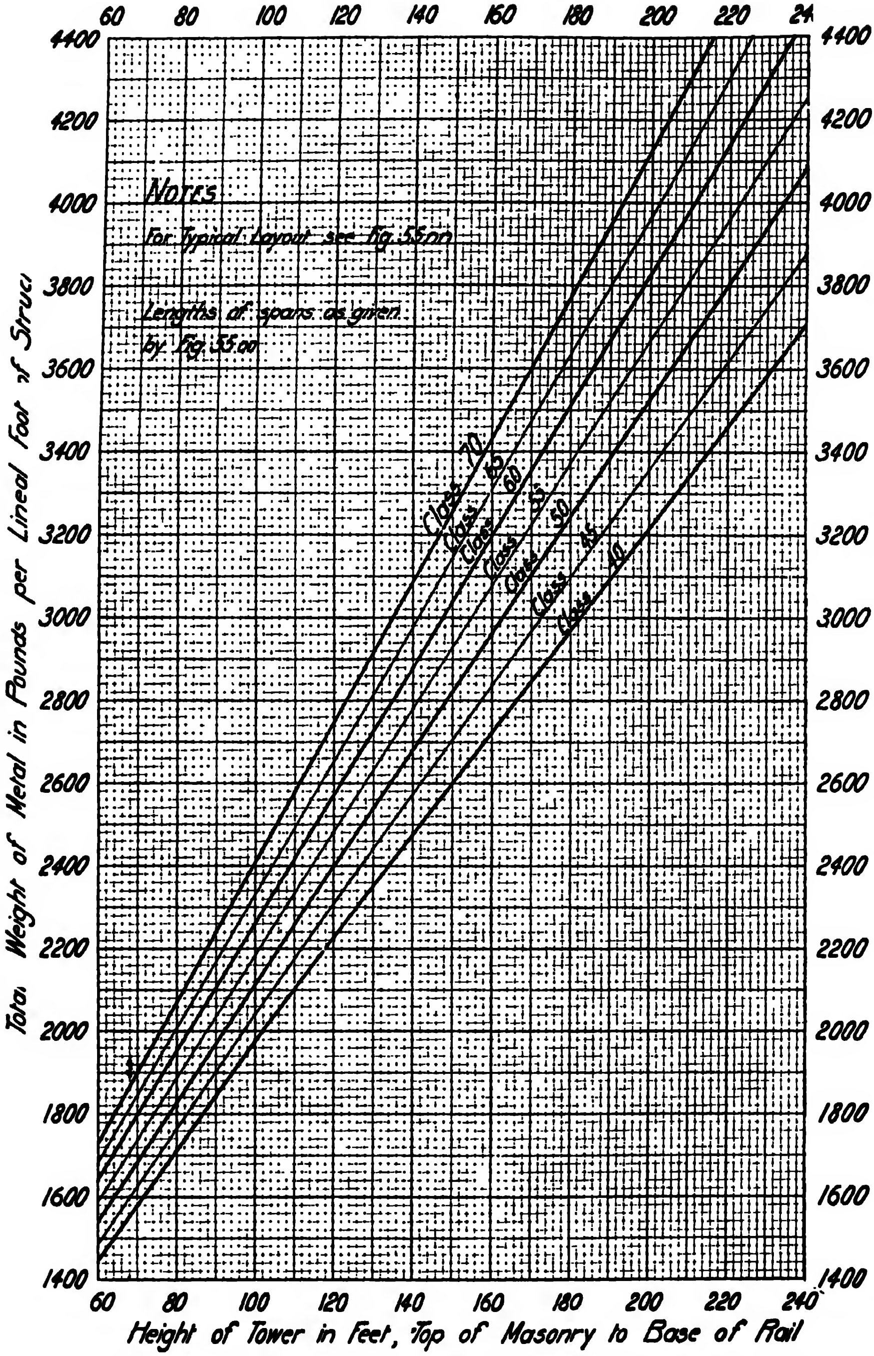
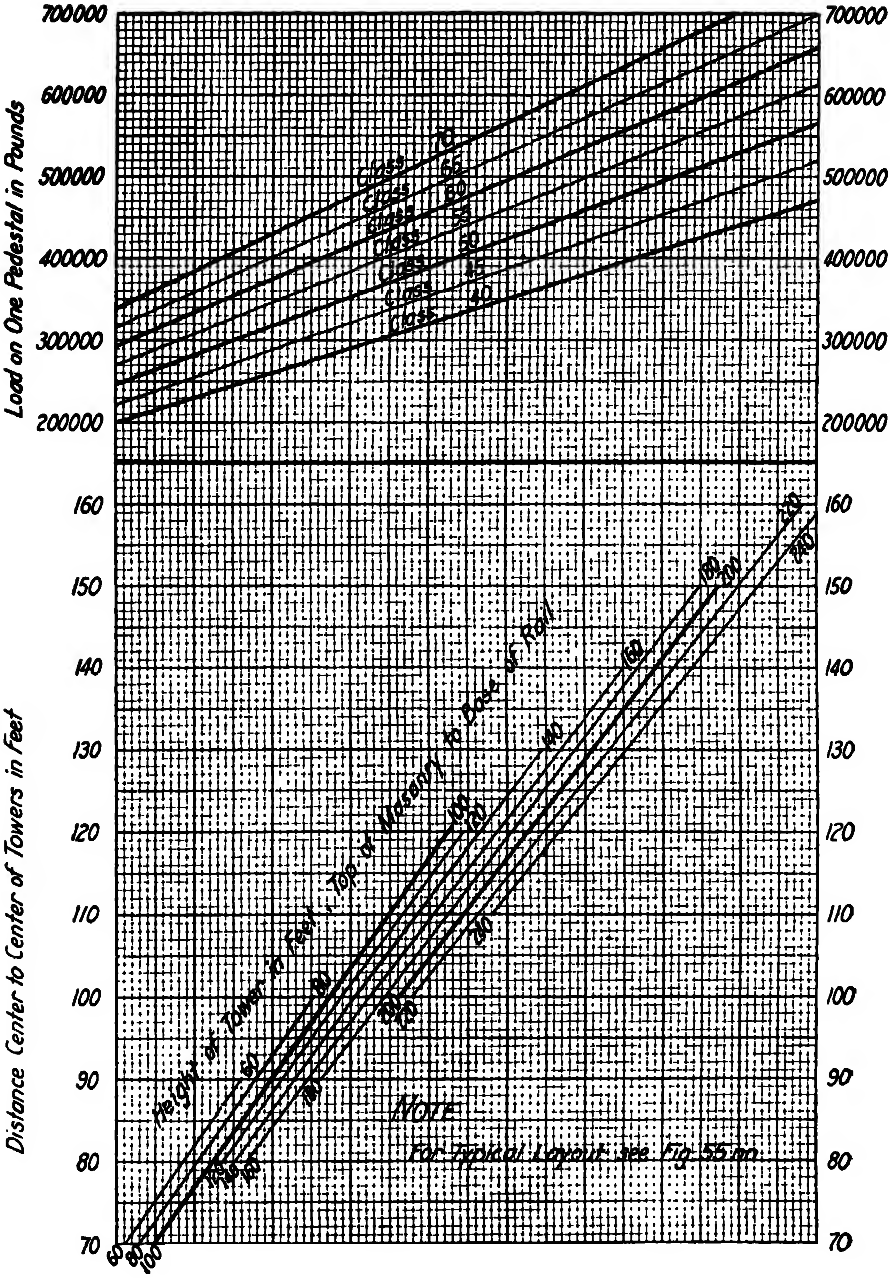


FIG. 55rr. Single-track-railway Trestles, Type I—Total Metal in Trestles for Economic Layouts.



NOTE.—Enter lower portion of diagram with the height of tower and the distance centre to centre of towers, and trace vertically upward to the curve for the live load.

FIG. 55ss. Single-track-railway Trestles, Type I—Approximate Maximum Loads on Tops of Pedestals.

diate spans, the weights of metal in bents and towers per lineal foot of structure. (It was found impossible to combine these curves into one "double tracing" diagram, as was done in Fig. 55uu and Fig. 55vv.)

The approximate maximum loads on top of pedestals for trestles of

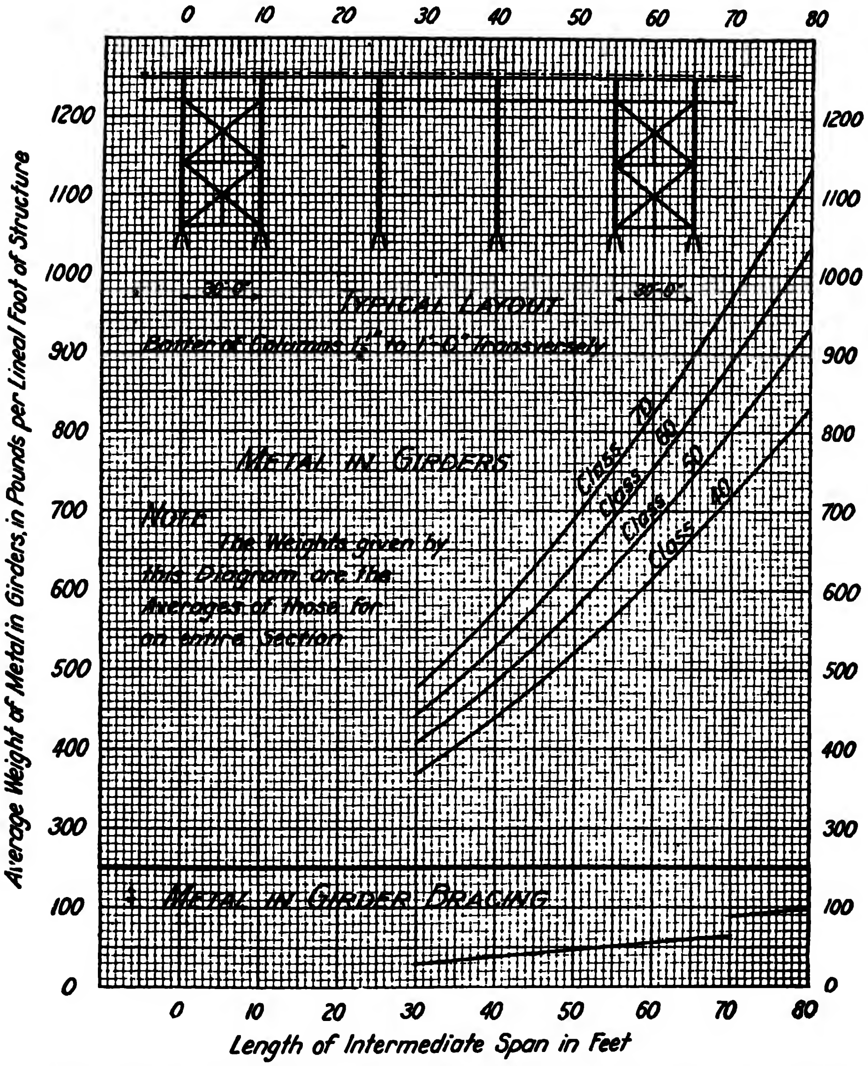
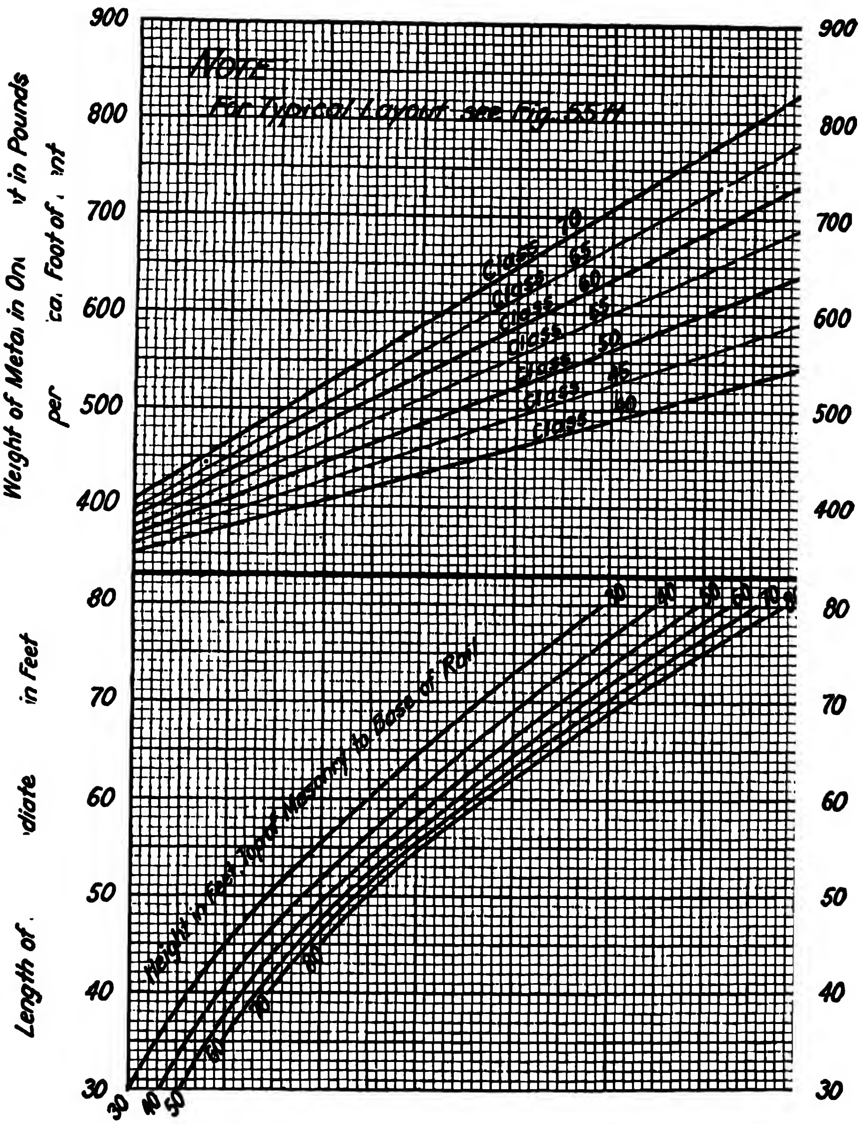


FIG. 55tt. Single-track-railway Trestles, Type II—Metal in Girders and Girder Bracing.

Type II can be found from Fig. 55ss, which was prepared especially for trestles of Type I. For the pedestals under the towers, it is necessary to enter with the sum of the lengths of one tower span and one intermediate span, instead of the distance from centre to centre of towers; and for the pedestals under the solitary bents, the sum of the lengths of two intermediate spans is to be used. For the tower pedestals the results

are exact; and for those under the solitary bents the errors involved are trifling.



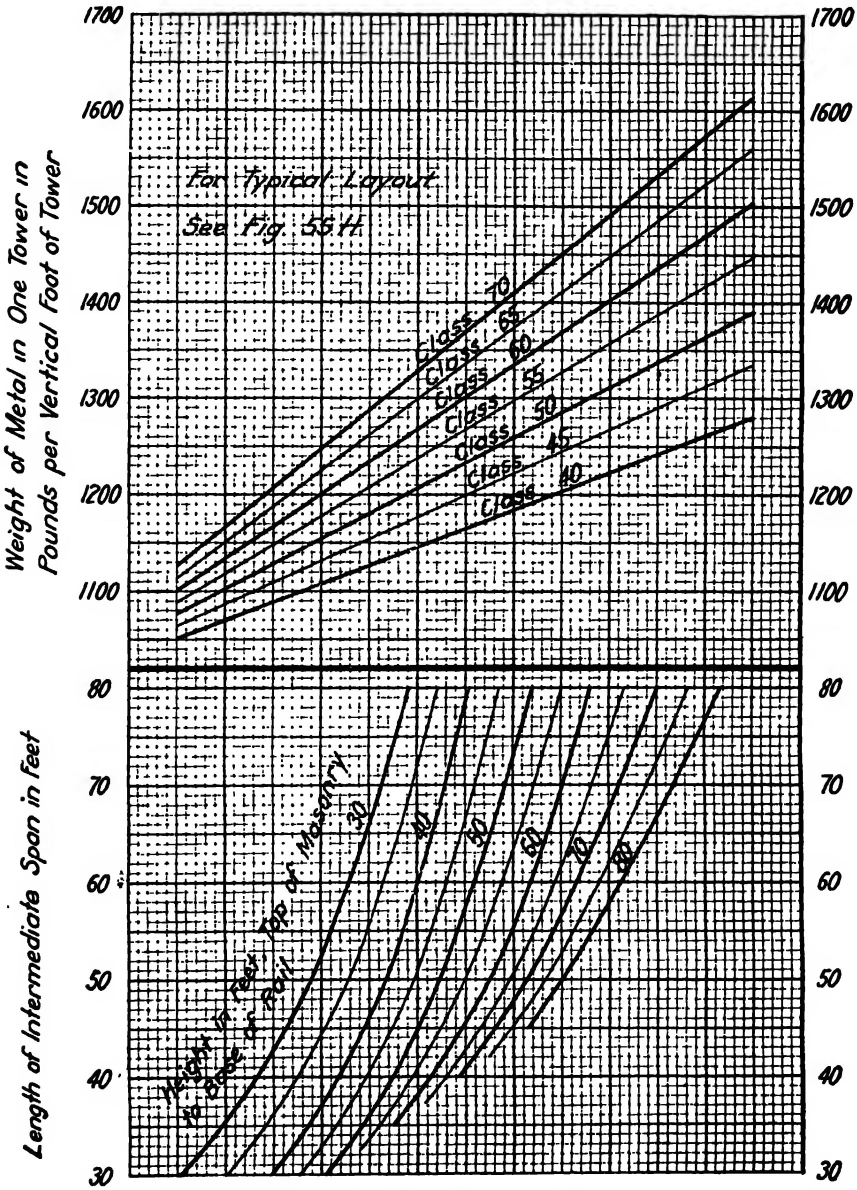
NOTE.—Enter lower portion of diagram with the height of tower and the length of intermediate span, and trace vertically upward to the curve for the live load.

FIG. 55uu. Single-track-railway Trestles, Type II—Metal in One Bent.

For trestles on curves, the weights given by the above diagrams are to be increased two per cent for each degree of curvature, as in the case of trestles of Type I.

Double-Track-Railway Trestles

The author has never had occasion to extend systematically his researches so as to cover double-track-railway trestles, although, of course, he has designed and built structures of that kind. A rough approxima-



NOTE.—Enter lower portion of diagram with the height of tower and the length of intermediate span, and trace vertically upward to the curve for the live load.

FIG. 55vv. Single-track-railway Trestles, Type II—Metal in One Tower.

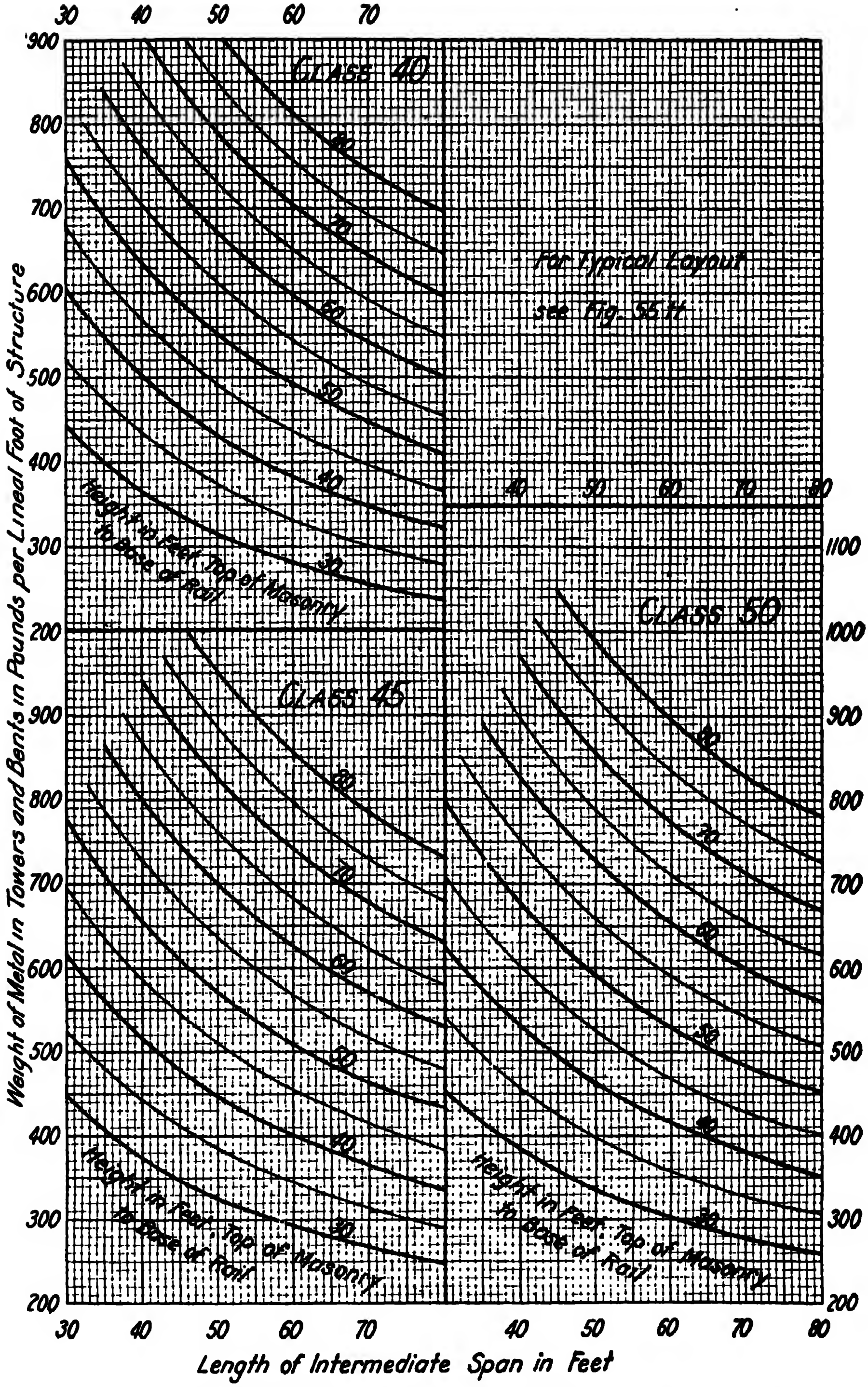


Fig. 55*ww*. Single-track-railway Trestles, Type II—Metal in Towers and Bents for Classes 40, 45, and 50.

tion for the weights thereof can be made from the preceding diagrams for single-track railway trestles as follows:

A. For weights of girders and girder bracing use twice those given for single-track trestles.

B. The weight of the longitudinal bracing in towers for double-

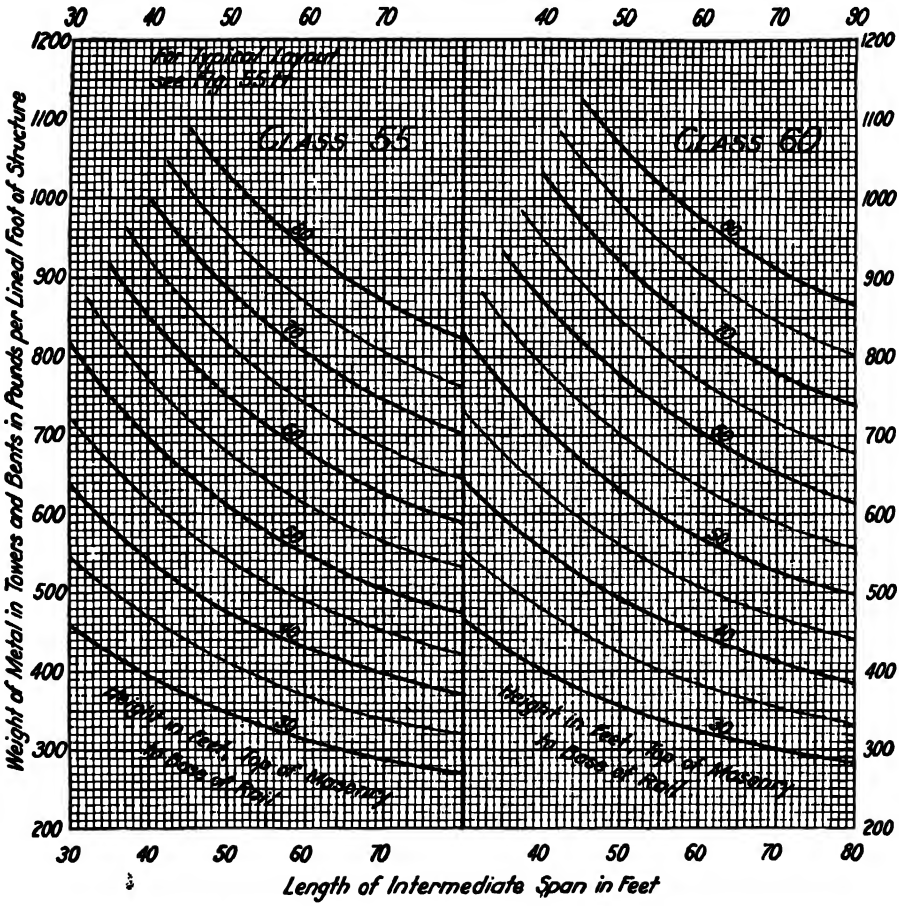


FIG. 55xx. Single-track-railway Trestles, Type II—Metal in Towers and Bents for Classes 55 and 60.

track trestles can be taken as one and eight-tenths (1.8) times that for single-track trestles, because, although the thrust of train is twice as great, the weight does not increase directly as the traction stresses.

C. The weight of the transverse bracing in towers for a double-track trestle, including that of the cross-girders at top of bents, can be taken as one and seven-tenths (1.7) times as great as that for a single-track trestle.

D. The weight of columns for a double-track trestle can be assumed as one and six-tenths (1.6) times that for a single-track trestle.

If one obtains the total weight of metal in a double-track railway trestle in the manner above indicated, he must not forget that his figures are merely approximate—accurate enough for a preliminary estimate only.

For double-track railway trestles on curves, the weights found in the

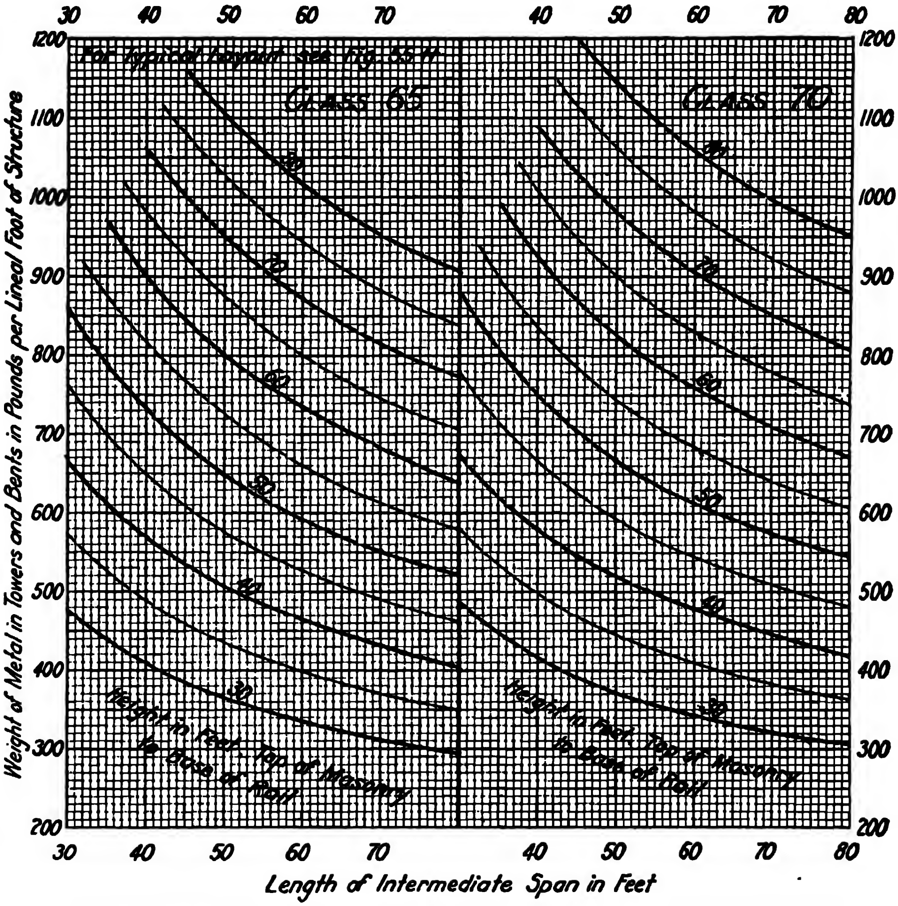


FIG. 55*yy*. Single-track-railway Trestles, Type II—Metal in Towers and Bents for Classes 65 and 70.

above manner from the diagrams are to be increased two per cent for each degree of curvature, as in the case of single-track trestles.

Electric Railway Trestles

In order to obtain the economic proportions for any single-track electric railway trestle, the equivalent uniform live load and the impact load for a span length of, say, eighty (80) feet should be computed, and the ratio of their sum to the sum of the corresponding live and impact loads for Class 40 railway loading should be figured. Call this ratio r.

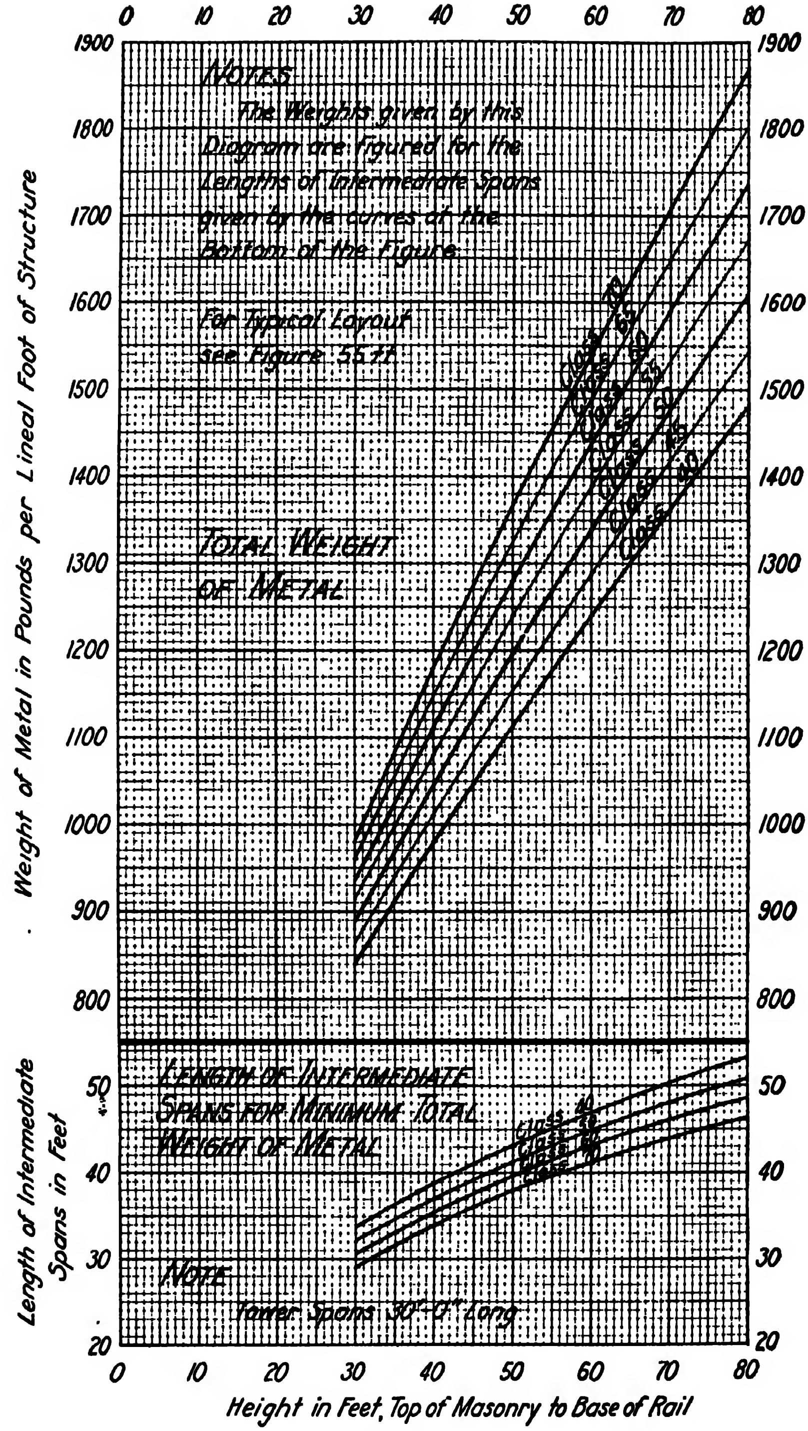


FIG. 55zz. Single-track-railway Trestles, Type II—Span Lengths and Total Metal in Trestles for Economic Layouts.

The electric railway trestle will then correspond to a steam railway trestle carrying a load of Class 40 *r*. The proper lengths of spans can then be esti-

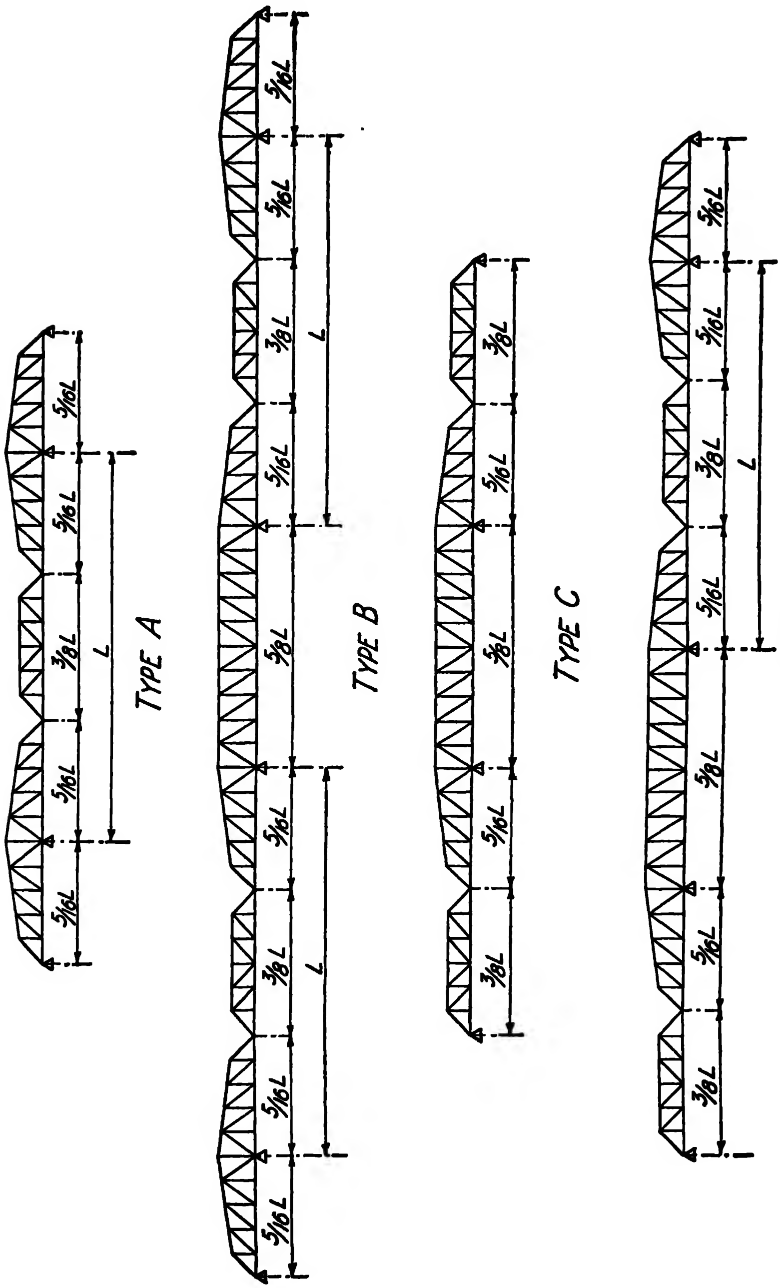
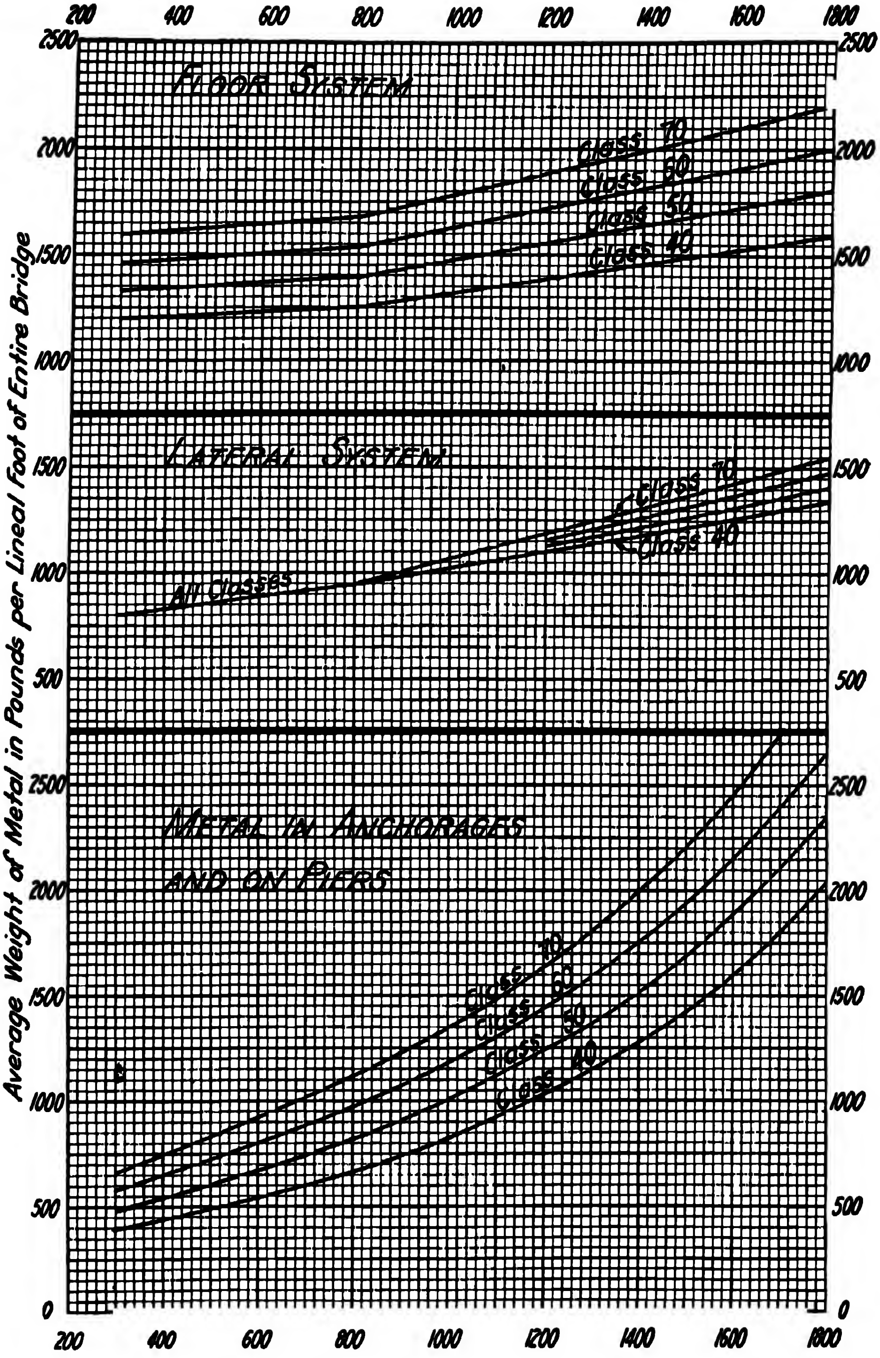


Fig. 55*aaa*. Typical Layouts for Double-track-railway, Cantilever Bridges.

mated by extrapolation from Fig. 55*oo* for a trestle of Type I, and from Fig. 55*zz* for one of Type II. The total loads per lineal foot of the girders


Floor System
Class 70
Class 60
Class 50
Class 40
Lateral System
All Classes
Class 70
Class 40
Metal in Anchorages and on Piers
Class 70
Class 60
Class 50
Class 40
Average Weight of Metal in Pounds per Lineal Foot of Entire Bridge
200
400
600
800
1000
1200
1400
1600
1800
0
500
1000
1500
2000
2500

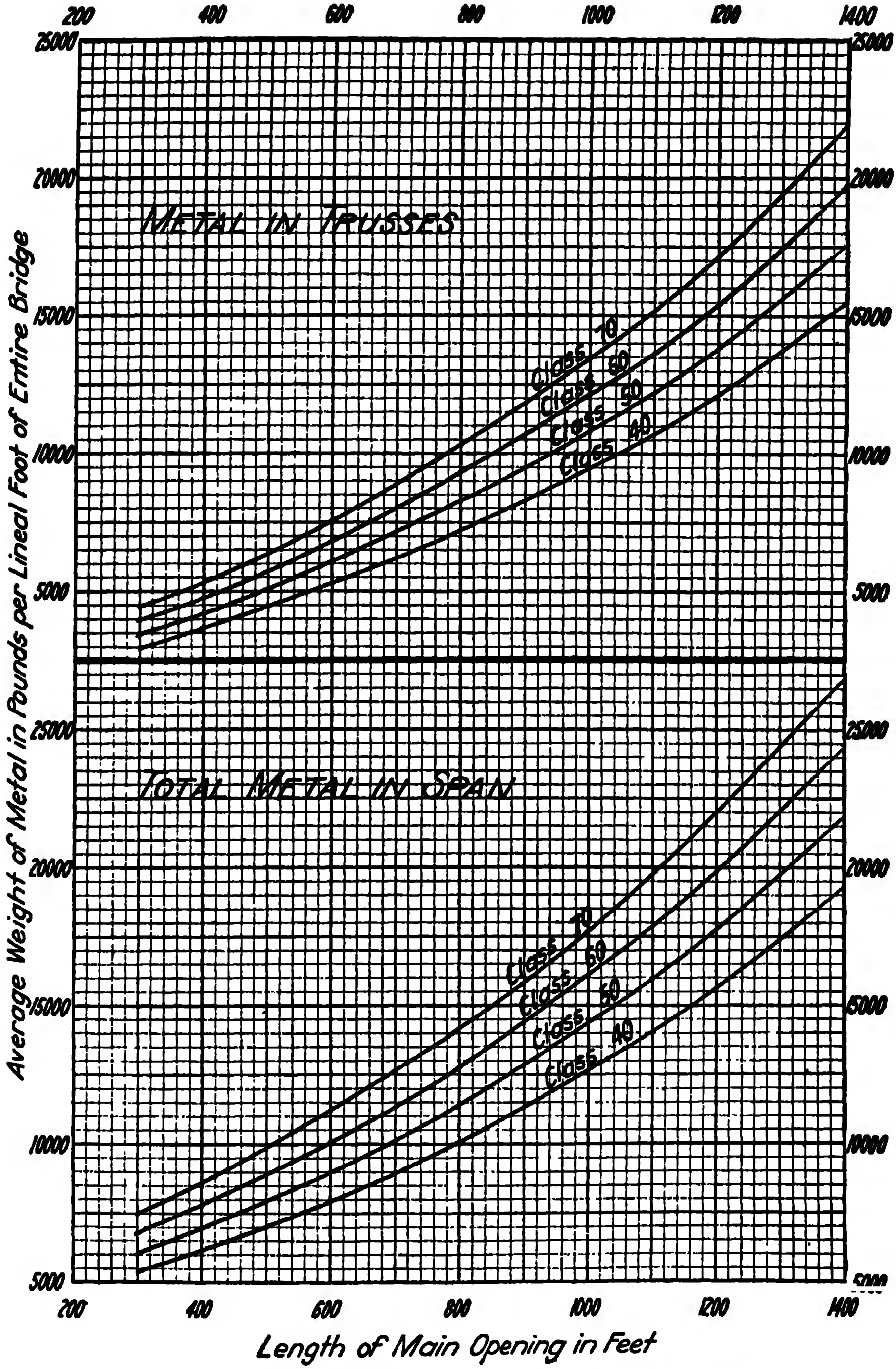


FIG. 55ccc. Double-track-railway, Riveted, Cantilever Bridges, Type A—Metal in Trusses and Total Metal in Bridge.

are then calculated, and their weights are determined from Fig. 55*ff*.

The weights of the girder bracing, of the longitudinal and transverse bracings of the towers, and of the transverse bracing of the bents will be about the same as in the case of a single-track-railway trestle, provided that $\frac{3}{8}''$ minimum thickness of metal be employed. If the use of $\frac{5}{16}''$ metal be permitted, the weights should be reduced twenty (20) per cent.

The weights of the columns can be found by the formula,

$$C_E = C_R \left(\frac{1 + 4r}{5}\right), \qquad \text{[Eq. 1]}$$

in which C_E = weight of columns for a single-track electric railway trestle,
C_R = weight of columns for single-track steam railway trestle, and
r = ratio of the live plus impact loads for the electric railway trestle to the live plus impact loads for the steam railway trestle, as above defined.

In case it be desired to apply the diagrams to a double-track electric railway trestle, it will be necessary first to figure the weights of metal for a single-track electric railway structure as just indicated, and then increase the weights of girders, of girder bracing, of transverse bracing in bents and towers, and of columns as previously explained for double-track railway trestles. The weight of the longitudinal bracing of the towers will be about the same as that for the single-track steam railway structure.

For electric railway trestles on curves, the weights found in the above manner are to be increased two per cent for each degree of curvature, as in the case of steam railway trestles.

The weights of electric railway trestles obtained as above are, of course, approximate only.

Cantilever Bridges

Cantilever bridges may be divided into four general types, as shown in Fig. 55*aaa*.

Type A consists consecutively of an anchor arm, a cantilever arm, a suspended span, a cantilever arm, and an anchor arm. This is the most commonly used of the four.

Type B consists consecutively of an anchor arm, a cantilever arm, a suspended span, a cantilever arm, a central anchor span, a cantilever arm, a suspended span, a cantilever arm, and an anchor arm.

Type C consists consecutively of a suspended span, a cantilever arm, an anchor span, a cantilever arm, and a suspended span, each of the two suspended spans being hung at one end to a cantilever arm and supported by a pier at the other.

Type D consists consecutively of a suspended span, a cantilever arm,

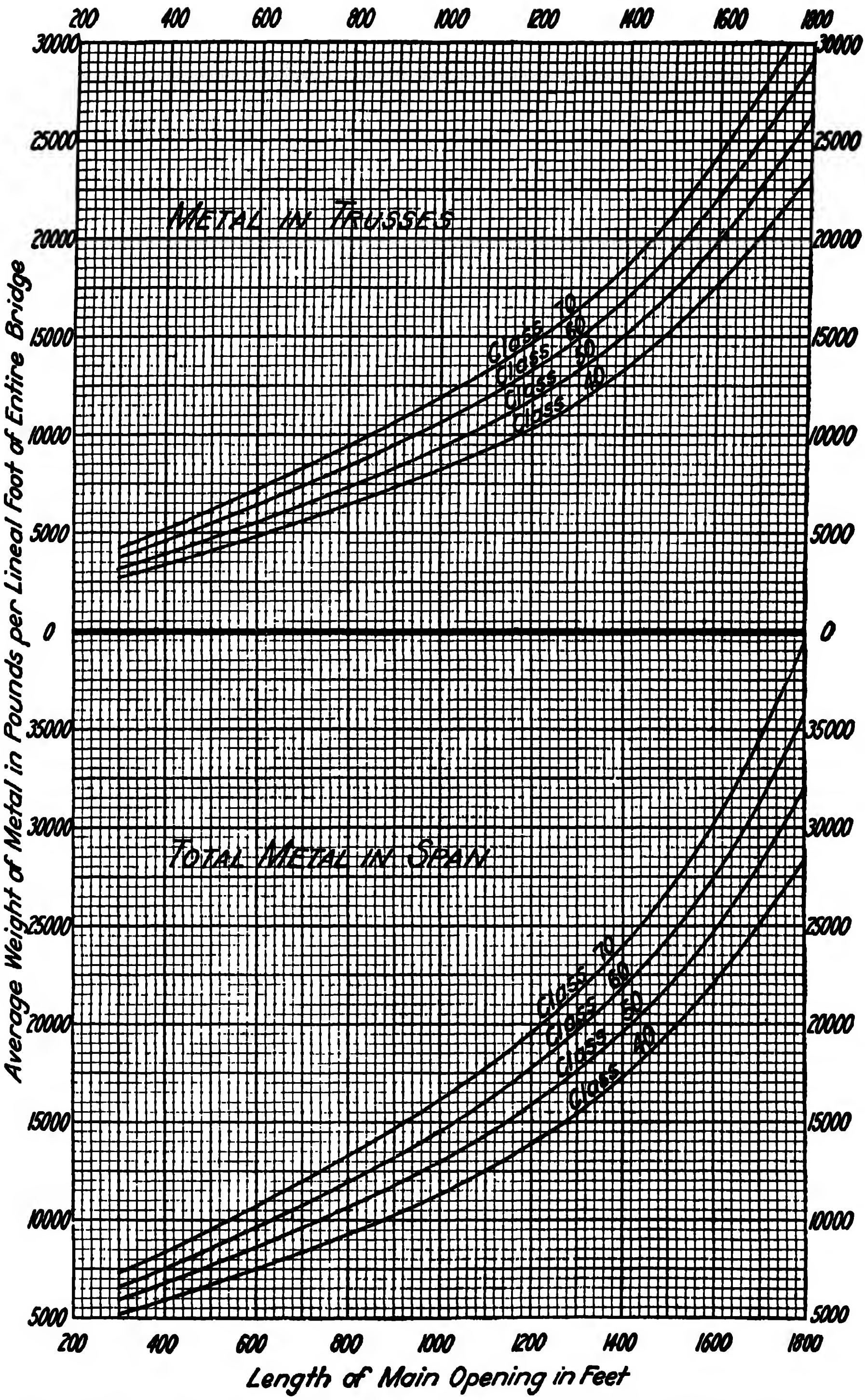


Fig. 55*ddd*. Double-track-railway, Pin-connected, Cantilever Bridges, Type A—Metal in Trusses and Total Metal in Bridge.

an anchor span, a cantilever arm, a suspended span, a cantilever arm, and an anchor arm, being similar to Class C at one end and to Class B at the other.

For the purpose of plotting weights of metal the following ratios have been assumed, as indicated in Fig. 55*aaa*. They are as nearly as may be the economic ones. Calling L the length of main opening, or that of a suspended span and two cantilever arms, the length of the suspended span is $3/8 L$, that of each cantilever arm and of each anchor arm is $5/16\, L$, and that of the anchor span is $5/8 L$.

The average weights of metal per lineal foot *for total length of structure* have been carefully figured for main openings varying in length from 300 to 1,800 feet, and have been plotted on the diagrams shown in Figs. 55*bbb* to 55*mmm*, inclusive. Figs. 55*bbb*, 55*eee*, 55*hhh*, and 55*kkk* give the weights of the floor system, lateral system, and metal in anchorages and on piers, for each of the four types of cantilevers. These weights are practically the same for riveted and for pin-connected spans. Figs. 55*ccc*, 55*fff*, 55*iii*, and 55*lll* record the weights of trusses and total metal in bridge for riveted structures; and Figs. 55*ddd*, 55*ggg*, 55*jjj*, and 55*mmm*, afford the same information for pin-connected bridges.

It should be noted that Type C gives the least weight per lineal foot for total length of structure; but this does not necessarily mean that it is the most economic, for the main opening provided is only eleven-sixteenths of that in the other types. A discussion of the economics of the four types of cantilevers will be found on page 587, *et seq.*

The curves for the weight of the pin-connected trusses were obtained by the direct designing of the trusses for a number of span lengths. Those for the riveted trusses were figured from the pin-connected curves, taking due account of the high percentage of details in heavy riveted trusses, which in the case of the Fratt Bridge over the Missouri River at Kansas City ran as high as fifty per cent, instead of the usual thirty-five per cent for ordinary spans. The curves for the pin-connected spans have been carried out to a length of 1,800 feet, and those for riveted spans to 1,400 feet. The use of riveted trusses for spans as long as the latter limit is very unlikely.

TRANSFORMATION FORMULÆ

It is often advantageous to know how to obtain the weight of metal per lineal foot of span for any portion of a bridge when the corresponding weight for that portion of a similar bridge is known. For instance, if the truss weight or the floor weight for a certain bridge and a certain loading be given, what would be the corresponding weight for a similar bridge having a heavier or a lighter load? Or, if the truss weight per lineal foot of span for a certain live load and a certain span length be known, what would be the corresponding weight per foot for the same live load in a longer or a shorter span? Or, if the truss weight or the

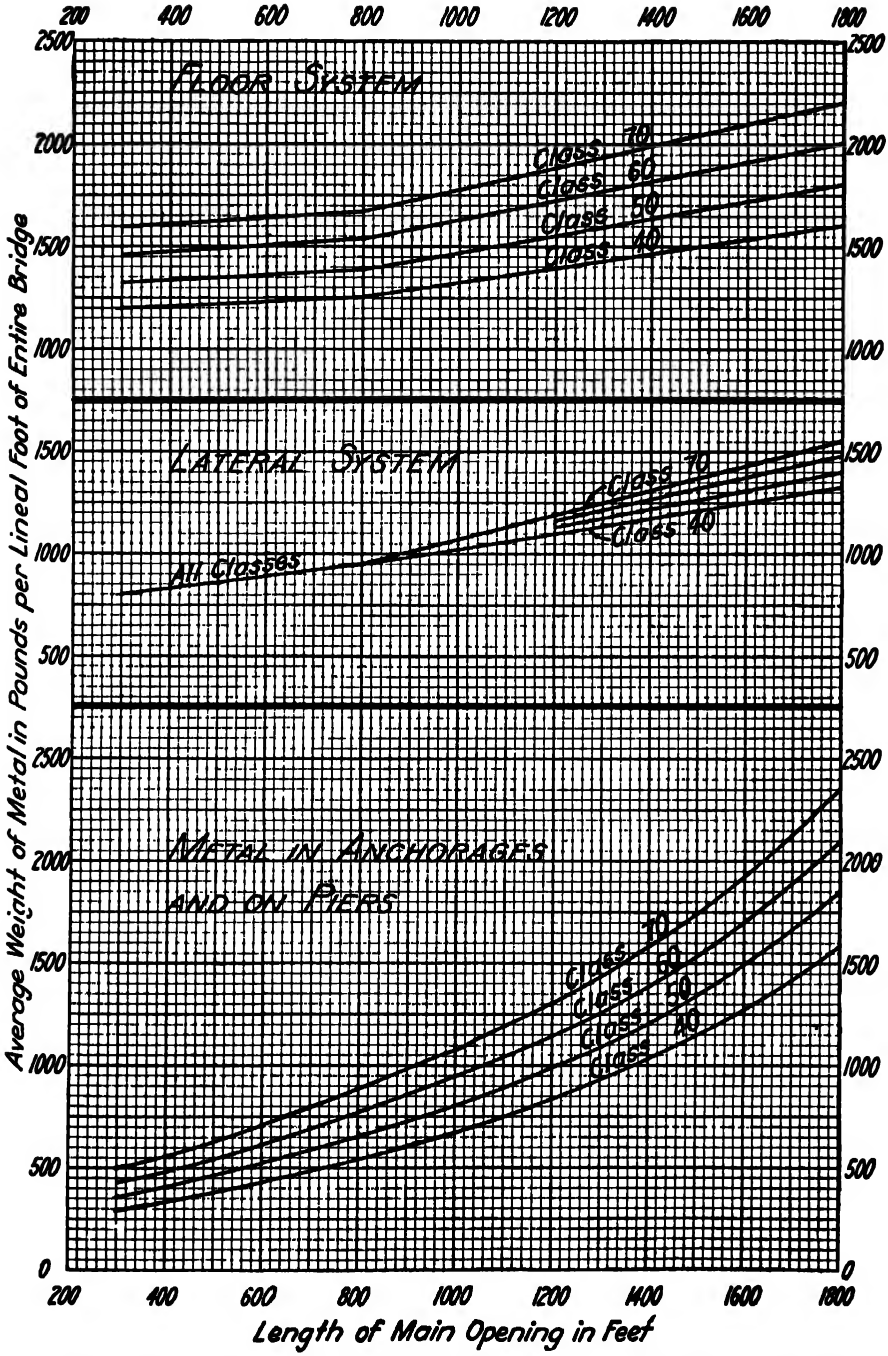


FIG. 55eee. Double-track-railway, Cantilever Bridges, Type B—Metal in Floor System, Laterals, and on Piers.

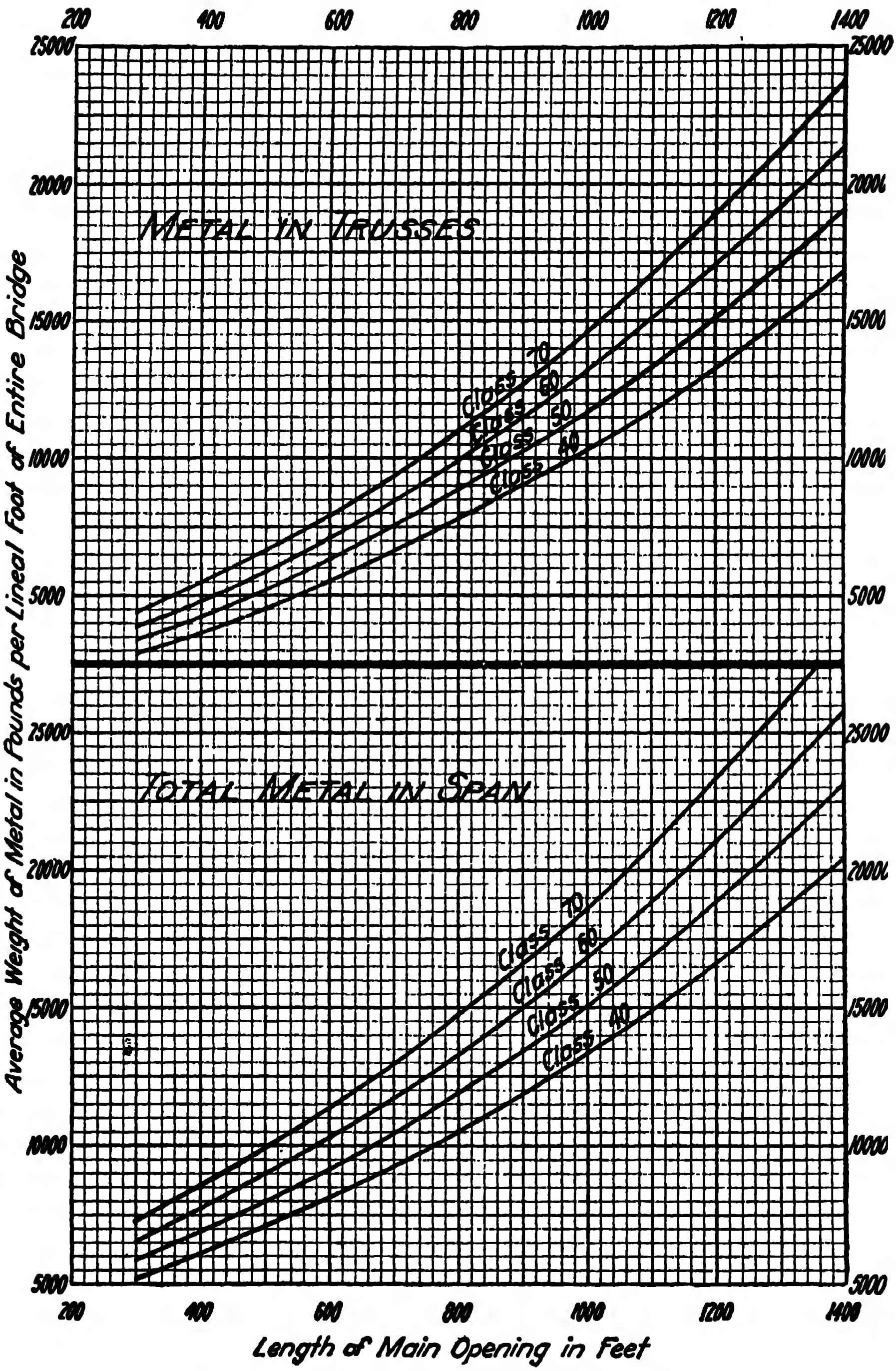


FIG. 55*fff*. Double-track-railway, Riveted, Cantilever Bridges, Type B—Metal in Trusses and Total Metal in Bridge.

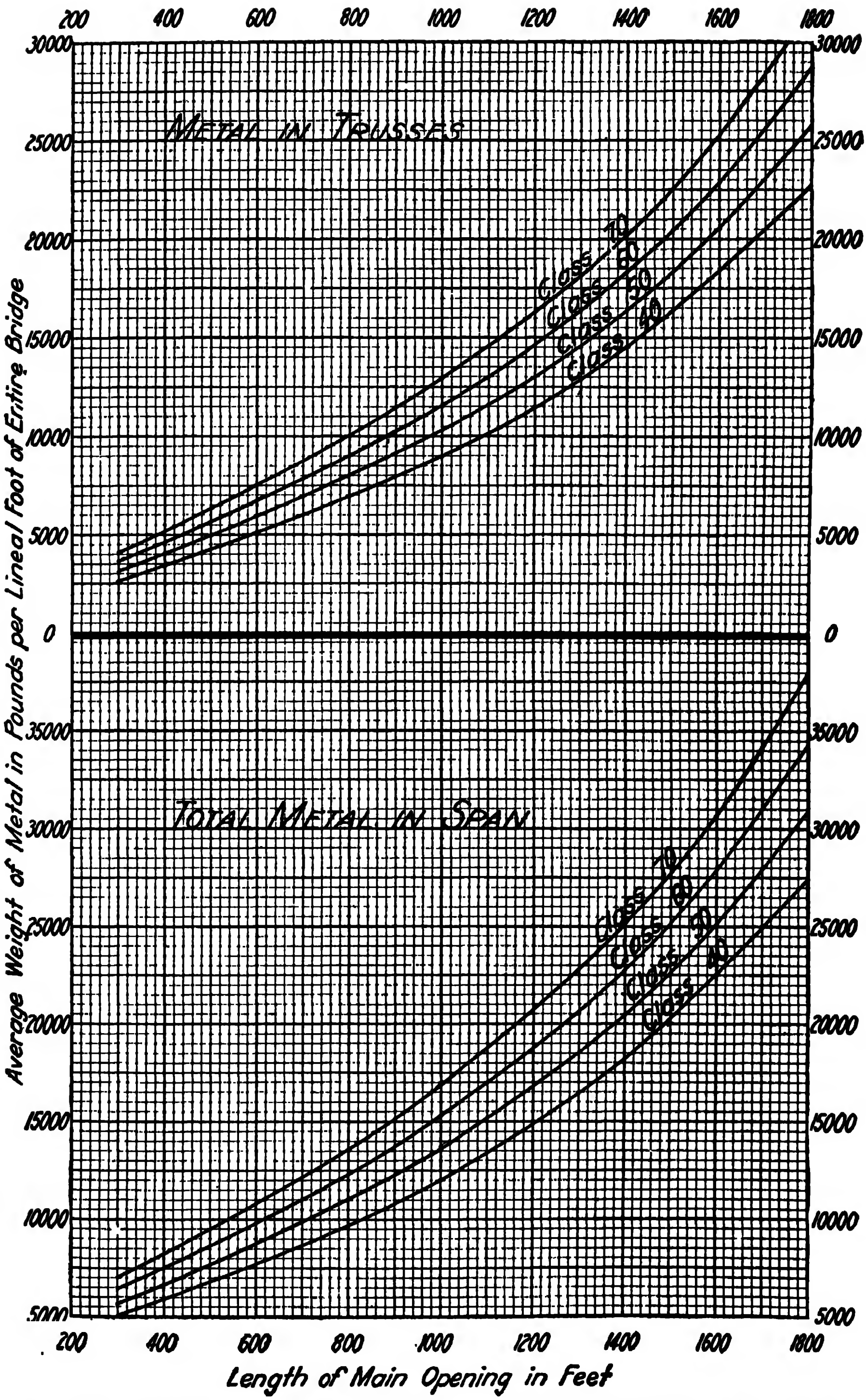


FIG. 55ggg. Double-track-railway, Pin-connected, Cantilever Bridges, Type B—Metal in Trusses and Total Metal in Bridge.

floor weight per lineal foot of span for a carbon steel bridge be known, what would be the corresponding weight for a similar bridge manufactured from an alloy steel of a certain elastic limit?

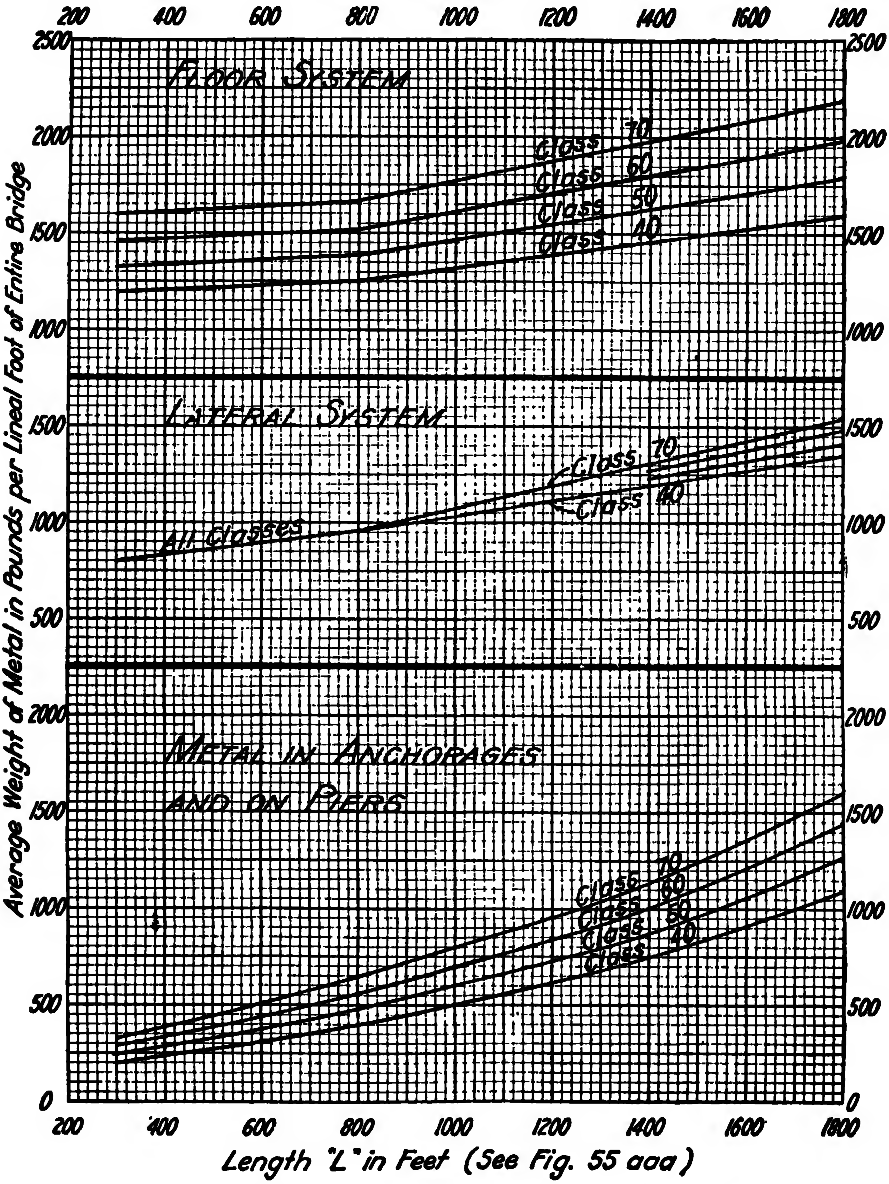


FIG. 55*hhh*. Double-track-railway, Cantilever Bridges, Type C—Metal in Floor System, Laterals, and on Piers.

For many years the author has studied deeply the theory of such weight variation and from time to time has given some of the results

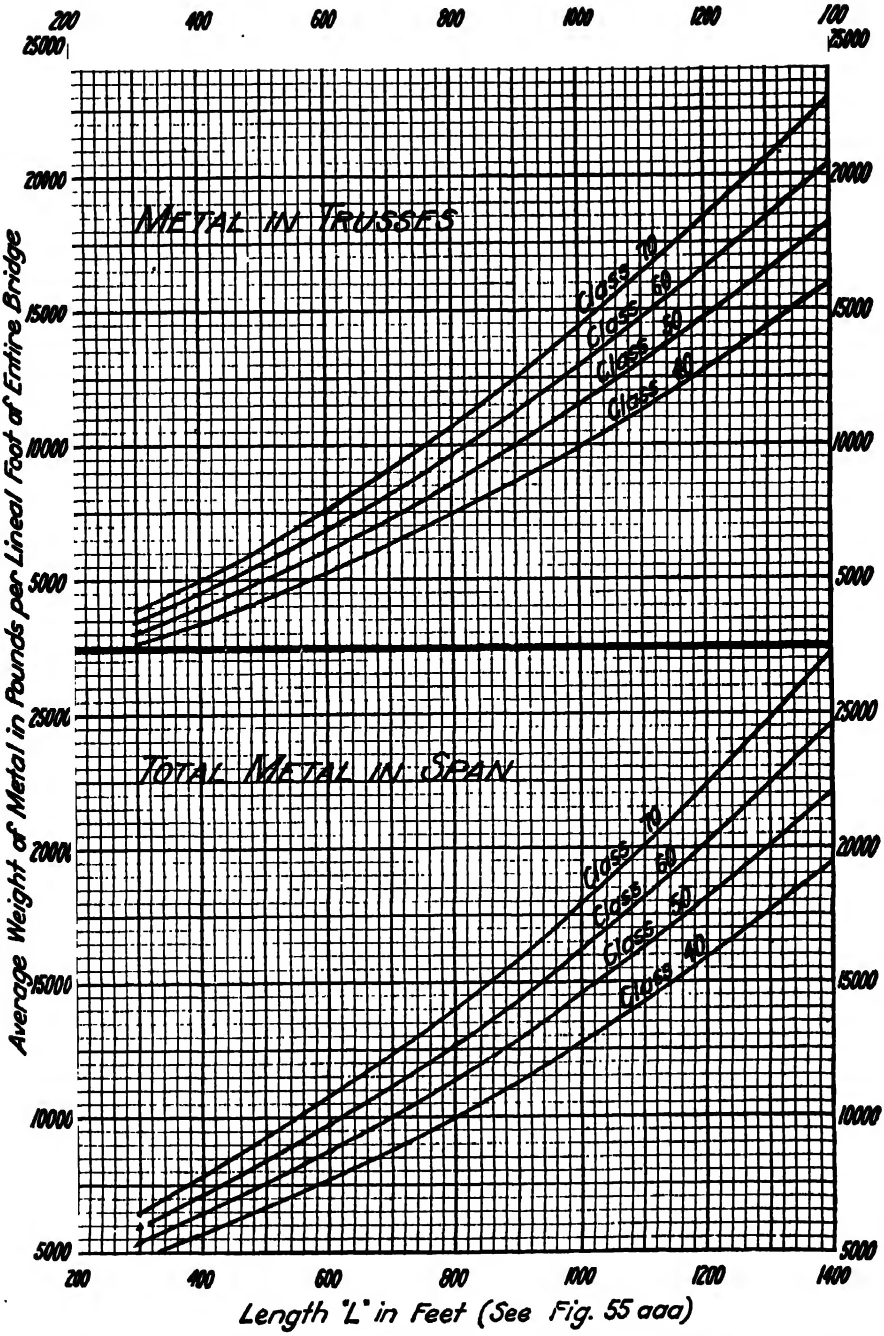


FIG. 55*iii*. Double-track-railway, Riveted, Cantilever Bridges, Type C—Metal in Trusses and Total Metal in Bridges.

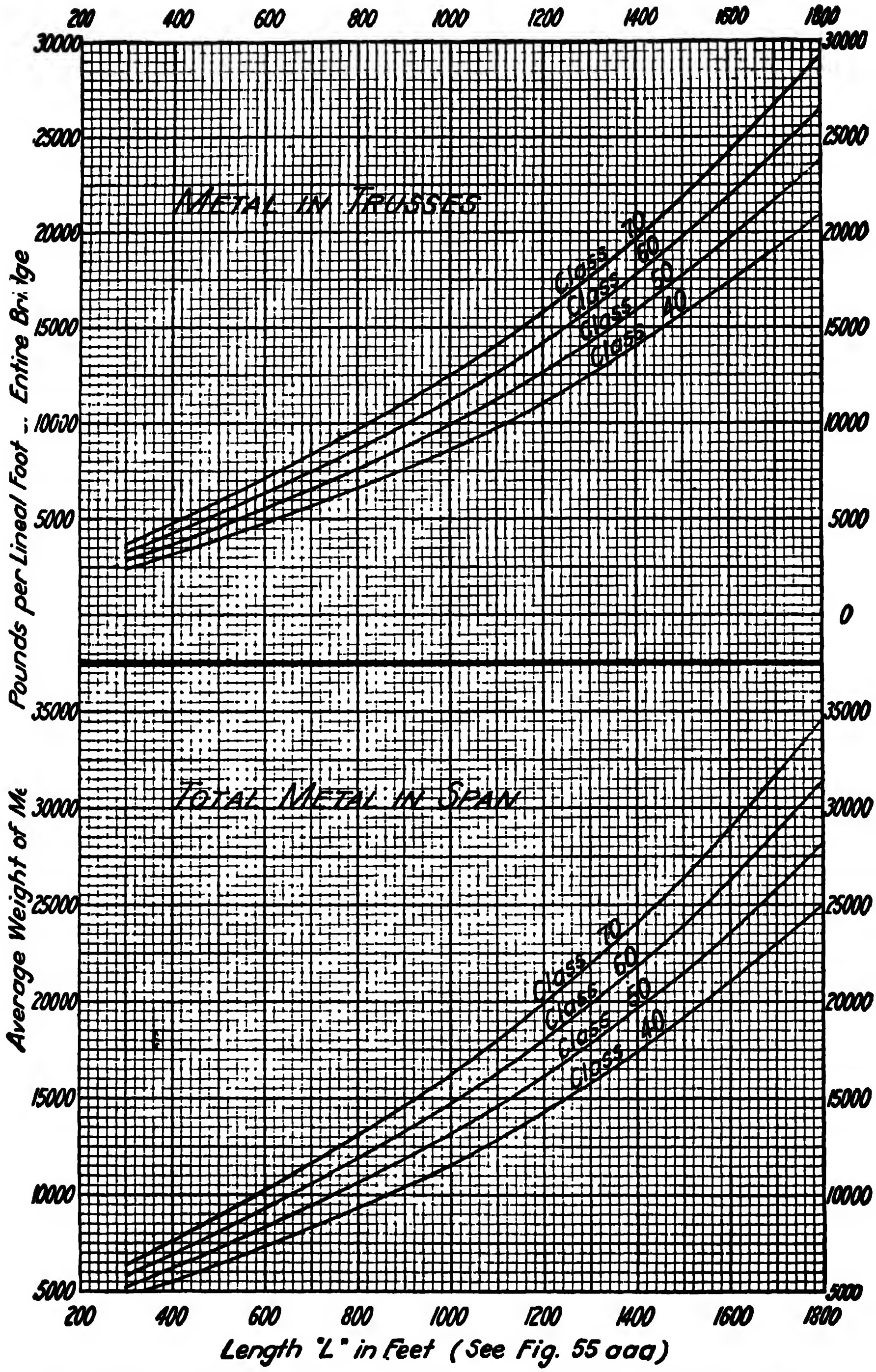


Fig. 555jjj. Double-track-railway, Pin-connected, Cantilever Bridges, Type C—Metal in Trusses and Total Metal in Bridge.

of his investigations to the engineering profession. He herewith reproduces the most important of all his findings.

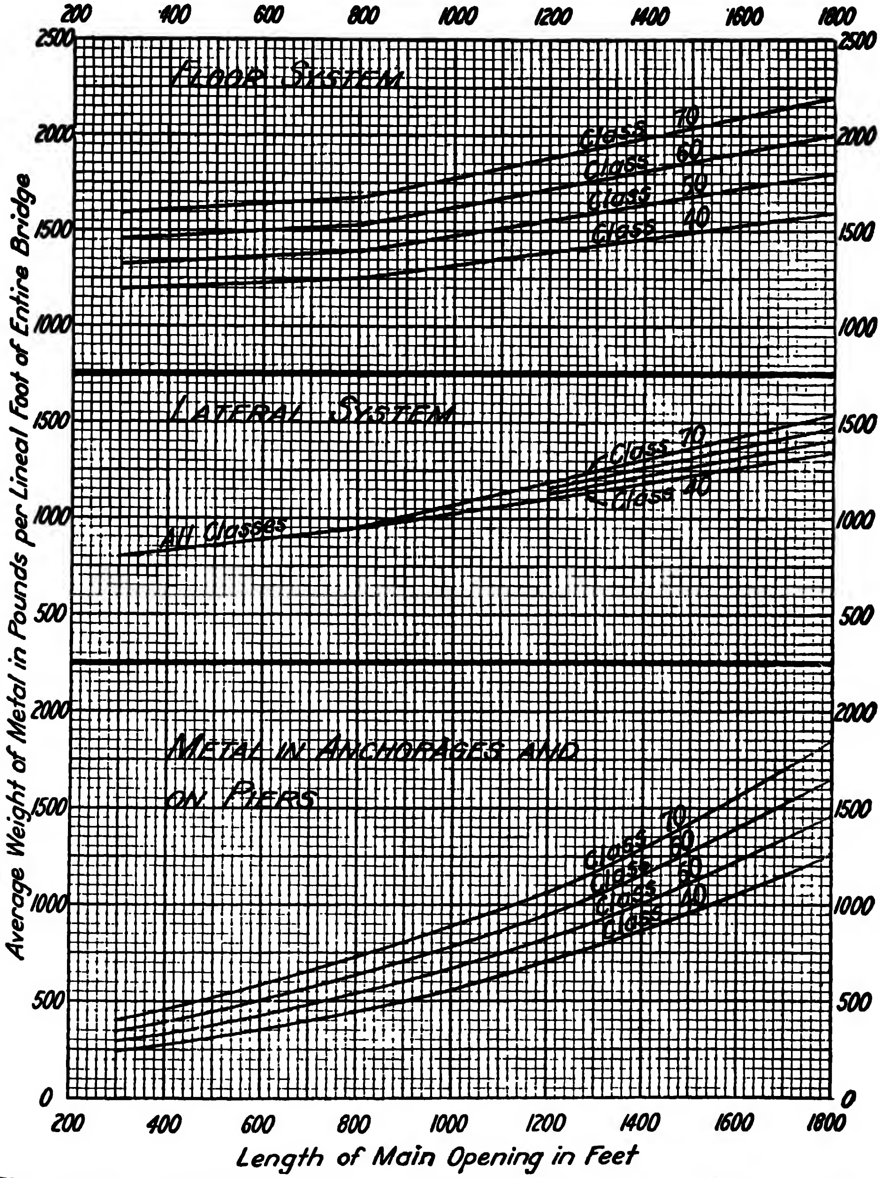


FIG. 55*kkk*. Double-track-railway, Cantilever Bridges, Type D—Metal in Floor System, Laterals, and on Piers.

To ascertain the weight per foot B' of the lateral system in a span of length l' from the corresponding known weight B in a span of length l, the following approximate formula may be used, provided the width of the superstructure remain unchanged:

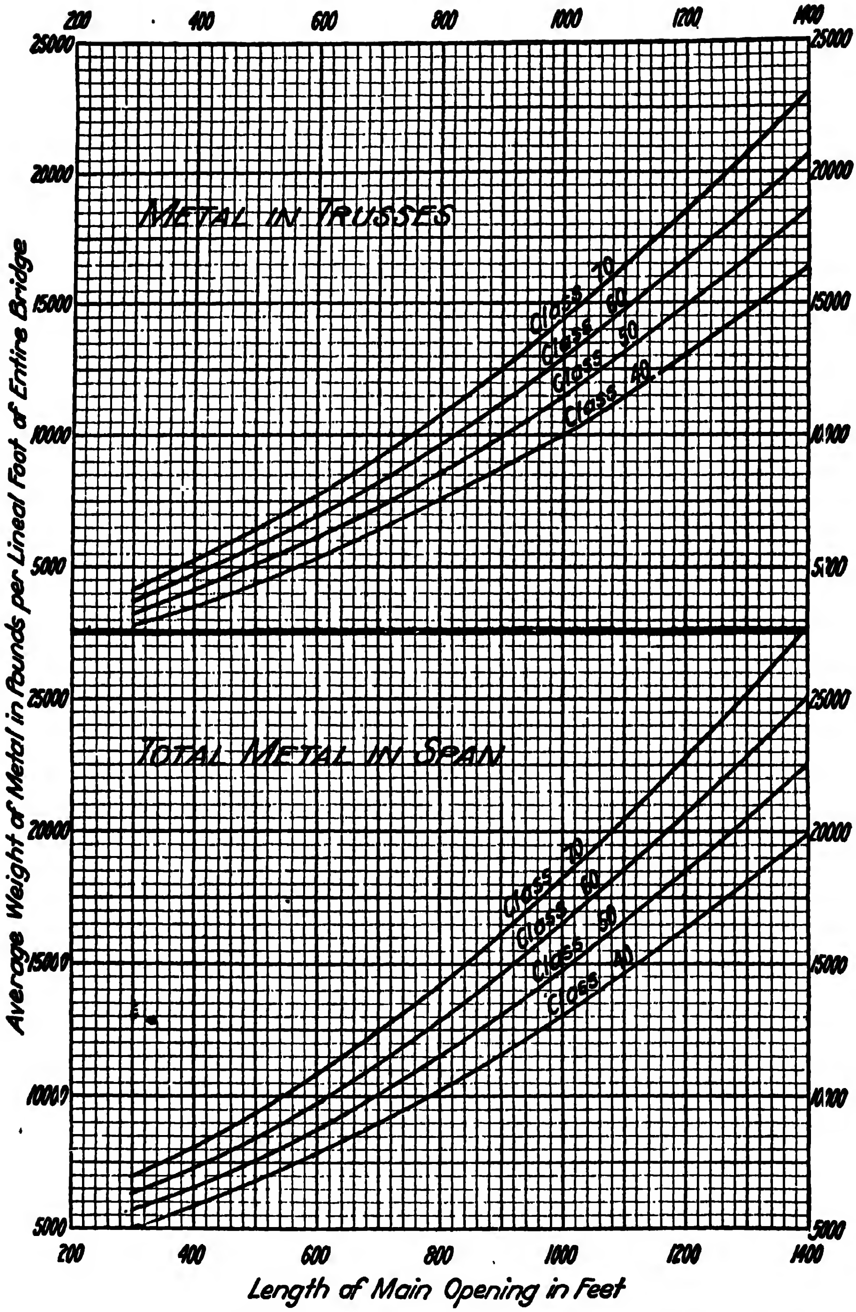


FIG. 55*lll*. Double-track-railway, Riveted, Cantilever Bridges, Type D—Metal in Trusses and Total Metal in Bridge.

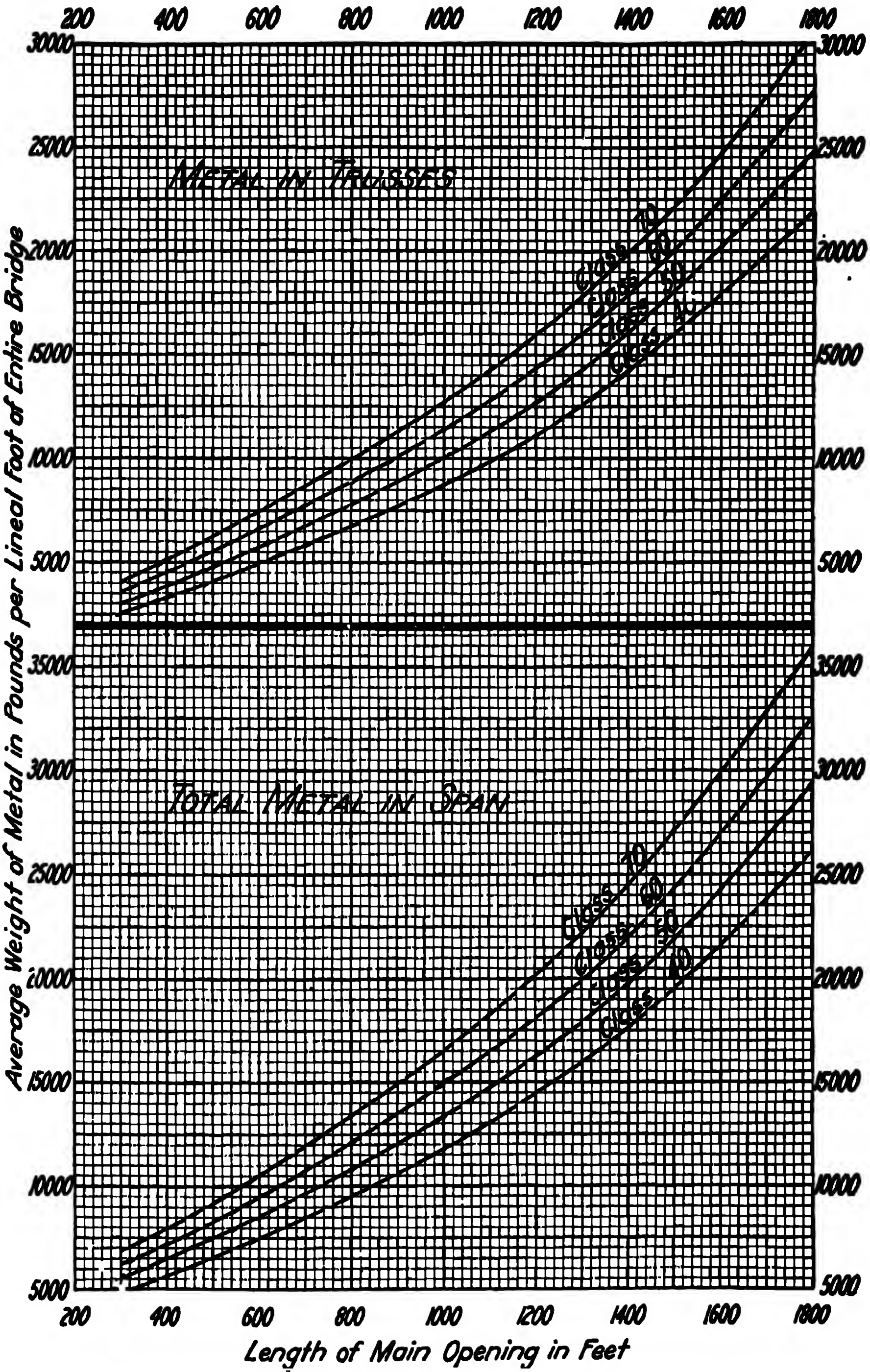


FIG. 55*mmm*. Double-track-railway, Pin-connected, Cantilever Bridges, Type D—Metal in Trusses and Total Metal in Bridge.

$$B' = B + \frac{l' - l}{2}, \qquad \text{[Eq. 2]}$$

where B and B' are expressed in pounds and l and l' in feet.

Should the width be changed, the new weight will have to be modified accordingly, under the assumption that the weight increases about one-half as rapidly as does the width.

This formula, which is absolutely illogical, in that it adds together pounds and feet, holds almost exactly true for single-track spans up to 350 feet in length and for double-track spans up to 500 feet in length. It applies fairly well also to single-track spans between 350 and 600 feet long when the modification above mentioned for increased perpendicular distance between central planes of trusses is duly considered.

To find the weight of floor system F' for an equivalent uniform live load per lineal foot w' from the weight F for a corresponding load w, the following approximate formula may be used:

$$F' = F\left(a + (1 - a)\frac{w'}{w}\right), \qquad \text{[Eq. 3]}$$

where a is 0.6 for single-track bridges and 0.5 for double-track bridges. Theoretically it would have been more logical to let the values of w and w' represent the sums of live load, impact, and dead load, which would have reduced the values of a; but it saves time to use live loads only in finding the ratio of reduction. Letting the ratio $\frac{w'}{w} = r$, the formula for single-track bridges will be

$$F' = F(0.6 + 0.4r); \qquad \text{[Eq. 4]}$$

and that for double-track bridges will be

$$F' = F(0.5 + 0.5r). \qquad \text{[Eq. 5]}$$

To find the truss weight T' per lineal foot of span of length l' from the corresponding known weight T for a span of length l, the live load per lineal foot remaining unchanged, the following approximate formula will serve for spans of ordinary length—say up to five hundred feet long,

$$T' = T\frac{l'}{l}; \qquad \text{[Eq. 6]}$$

while for longer spans there may be used the formula,

$$T' = \frac{T}{2}\left[\frac{l'}{l} + \left(\frac{l'}{l}\right)^2\right]. \qquad \text{[Eq. 7]}$$

To find for any span length the truss weight T' per lineal foot for

a total load p' per lineal foot from the corresponding known weight T for a load p, the following approximate empirical formula may be used,

$$T' = T\left(0.2 + 0.8\,\frac{p'}{p}\right). \qquad \text{[Eq. 8]}$$

This is quite accurate for all ordinary spans, but for very long ones it gives too great a variation between T' and T. After finding the value of T', the value used for p' should be checked; and if there be any serious disagreement between the value assumed and that found, the substitution in the formula should be made anew, and so on until a satisfactory agreement between the said values of p' be obtained.

The following approximately correct formulæ for weights per lineal foot of trusses have been derived from the diagrams given in this chapter. They are offered as a convenience to any one who cares to copy them into his notebook. In them l is the span length in feet, W is the weight in pounds of one truss per lineal foot of span, and P is the total load in pounds per lineal foot carried by the truss. They should not be used for lengths much beyond the limits noted.

TABLE 55*a*

FORMULÆ FOR TRUSS WEIGHTS

Type of Truss	Range of l (Feet)	Range of P (Pounds)	Formula
Through Riveted Pratt with Parallel Chords..	100–200	3,000–18,000	$W = 180 + \frac{(l-50)\,P}{1480}$
Through Riveted Pratt with Polygonal Upper Chords..............	200–300	3,000–18,000	$W = 180 + \frac{(l-70)\,(P+300)}{1370}$
Deck Riveted Pratt with Straight Bottom Chords.	100–200	3,000–13,000	$W = 180 + \frac{(l-30)\,P}{1590}$
	200–300	3,000–13,000	$W = 180 + \frac{(l-80)\,P}{1130}$
Through Pin Pratt with Polygonal Upper Chords............	190–350	3,000–18,000	$W = \frac{(l-25)\,(P+1700)}{1800}$

The formulæ in Table 55*a* can be employed instead of Equations 5 and 7, if desired, as they will give more accurate results. If the weight of one truss designed under some given specification is known, it can be substituted for W in the proper formulæ, and a new value of the denominator of the term involving l and P can then be computed. This procedure provides a formula which will apply quite closely for the given specification.

Instead of employing the formulæ of Table 55*a*, similar results can be obtained by finding the ratio of a known truss or girder weight under a given specification to the weight for a similar truss or girder of the same

span-length and loading as diagrammed in Figs. 55*ff* to 55*ll*, inclusive, and assuming this ratio to be the same for any other span and loading.

If a railway bridge is to be designed for substantially the same unit stresses as those of Chapter LXXVIII, but for a different loading or impact than those adopted for this treatise, the following method should be employed, as it is simple and very accurate. First find the sum of the equivalent uniform live load and the impact load, assuming a loaded length equal to one and one-half panels, for the specified loading, and also for Class 50 of this treatise; and call the ratio of the first sum to the second one r. The said loading is then equivalent to Class 50 $\times r$, so far as the floor system is concerned; and the floor system weight for this equivalent class is then read (by interpolation if necessary) from the proper curve. The equivalent class of loading for the full span-length is then found in a similar manner, and the weights of the laterals, metal on piers, and the trusses are determined from the proper curves. Unless either the arrangement of the locomotive axles or the impact curve is much unlike that of this treatise, it will be sufficiently accurate to compute merely the equivalent class of loading for the full span-length, and then employ the proper curve for the total weight of metal in the span. If a Cooper standard loading be adopted, and the impact formulæ of this treatise be employed, the curves will give the weights directly with a small margin on the safe side. If a Cooper loading be used with some other impact formula, the equivalent class of loading will be equal to the said Cooper loading multiplied by the ratio

$$\frac{1 + I'}{1 + I}$$

where I' is the impact adopted, and I is that given by the formula of this treatise. The same method will, of course, apply if the standard loadings of this treatise be used with some other impact formula.

From the author's paper on "The Possibilities in Bridge Construction by the Use of High Alloy Steels" are made the following extracts relating to the finding of metal weights in alloy steel bridges from those in similar carbon steel bridges and to the theory of weight curve extensions beyond the limits of actually designed structures.

"The following are the formulæ of reduction used in passing from known weights of metal per lineal foot of span in carbon-steel bridges to the corresponding weights in alloy-steel bridges. An observation of the nomenclature will show that the unaccented capital letters severally represent weights of metal per lineal foot of span in carbon-steel bridges (or otherwise known weights of bridges of any kind of steel), and the accented capital letters, the corresponding weights for alloy-steel bridges (or otherwise the corresponding unknown weights of bridges of some other kind of steel), also that the small letters severally represent lineal dimensions of structures, the main exceptions being that capital R is used for reactions and small r for ratios.

"*Floor System.*—

Let F = weight of metal per lineal foot of span in the 'Floor System' of carbon-steel bridges;

L = ditto for 'Lateral System';
T = ditto for 'Trusses';
P = ditto for 'On Piers' including anchorage material in the case of cantilever bridges.

"A certain portion of the weight of the floor system will vary inversely with the elastic limit of the steel, and the remainder will be invariable.

Let V = the variable portion,
and I = the invariable portion.

Then
$$F = V + I. \qquad \text{[Eq. 9]}$$

Let F' = the weight of metal per lineal foot of span in the floor system of alloy-steel bridges,
and r (greater than unity) = the ratio of elastic limits of alloy steel and carbon steel.

Then
$$F' = I + \frac{V}{r}. \qquad \text{[Eq. 10]}$$

"In heavy, double-track bridges, and especially those of long span, I will be approximately 0.35 F, and V approximately 0.65 F, hence

$$F' = 0.35\,F + \frac{0.65\,F}{r} = F\left(0.35 + \frac{0.65}{r}\right). \qquad \text{[Eq. 11]}$$

"In dealing with spans of greater length than any of those yet actually computed, it must not be forgotten that the increasing width of structure will augment the weight of the floor-beams and, consequently, the weight of metal per lineal foot of span for the floor system. In case of double-track cantilever bridges, an economy can be effected by widening the cantilever arms and the anchor arms uniformly from ends to supporting pier; but it is probable that motives of policy would lead the projectors to construct exceedingly long spans so as to carry more than two tracks.

"*Lateral System.*—

Let l_1 = length of span at which it pays to begin to use high steel for the laterals beyond the ends of l_1, it being assumed that the weight of laterals is uniform over the entire length l_1, or, in other words, that minimum sections are used therein throughout;
R_1 = wind reaction at end of l_1;
R = wind reaction at end of span l;
r_w = ratio (greater than unity) of R and R_1;
L_1 = weight of carbon steel per lineal foot for lateral system over the length l_1;
L'_2 = weight of mixed carbon and alloy steels per lineal foot of span at end of span l.

Then
$$L'_2 = L_1\left(0.3 + 0.7\frac{r_w}{r}\right). \qquad \text{[Eq. 12]}$$

"Let L'_a = average weight of metal per lineal foot for entire span l.

Then
$$L'_a = \frac{1}{l}\left\{ L_1\,l_1 + \frac{L'_2 + L_1}{2}(l - l_1) \right\}. \qquad \text{[Eq. 13]}$$

"Should L'_2 figure less than L_1, it shows that near the ends of the span minimum sections of the high steel must be used and that L'_a will equal L_1.

"In passing beyond the limits of actually figured spans, when computing the weights of metal in lateral systems, it must be remembered that, as just explained for the floor system, the weight per foot is increased, not only because of the greater span length but also because of the greater span width. As a rule, it may be stated that, for any very long span (the length thereof remaining constant), the effect of increasing the

width between central planes of trusses n per cent is to increase the weight of metal in the lateral system about $\frac{n}{2}$ per cent.

"*Trusses.*—In respect to the weight, T, of metal per lineal foot of span for trusses of carbon steel, the following equation may be used:

$$T = K + T_1 + C_c + C_w, \qquad \text{[Eq. 14]}$$

where K is the portion of the total truss weight per lineal foot which is independent of the quality of the metal and of the stresses; T_1 is that of the main portions of the tension members and of their details that are directly affected by the stresses; C_c is that of the main portions of the compression chords and inclined end posts and their details that are directly affected by the stresses; and C_w is that of the main portions of the compression web members.

"From experience in designing large bridges it may be stated that, as an average,

$$K = 0.2T,$$
$$T_1 = 0.3T,$$
$$C_c = 0.3T,$$

and

$$C_w = 0.2T.$$

"Both T_1 and C_c (and consequently their sum) will vary inversely with the elastic limit of the metal; but C_w, on account of the influence of the ratio of strut length to least radius of gyration, will not vary in that ratio. As an approximation it may be assumed that, in passing from any grade of steel to a higher grade, if, as before, r (greater than unity) is the ratio of the elastic limits of the two metals,

$$C'_w = \frac{1}{2} C_w\left(1 + \frac{1}{r}\right), \qquad \text{[Eq. 15]}$$

and

$$C'_c = \frac{C_c}{r}. \qquad \text{[Eq. 16]}$$

"Substituting these values in Equation 14, we have

$$T' = K + \frac{1}{r}\left(T_1 + C_c\right) + \frac{1}{2}C_w\left(1 + \frac{1}{r}\right). \qquad \text{[Eq. 17]}$$

"Substituting the values of K, T_1, C_c, and C_w in terms of T as previously given, we have

$$T' = T\left(0.3 + \frac{0.7}{r}\right). \qquad \text{[Eq. 18]}$$

"In finding the new truss weight per lineal foot for a higher steel, after computing it (as just indicated) for the direct effect of increased elastic limit, it must be corrected for the indirect effect, which is the changed total load per lineal foot for trusses. This correction is made thus:

"Find the sum of the live load, impact load, and dead load per lineal foot of span, for the known truss weight, T, and then determine approximately the corresponding sum (on the basis of an assumed final value of T'_f) for the new truss weight. Let the ratio of these sums (less than unity) be r_1.

Then

$$T'_f = T'\,(0.3 + 0.7\,r_1), \qquad \text{[Eq. 19]}$$

where T'_f is the final value of the truss weight. Combining Equations 18 and 19 gives

$$T'_f = T\left(0.3 + \frac{0.7}{r}\right)(0.3 + 0.7\,r_1). \qquad \text{[Eq. 20]}$$

"If the computed value of T'_f does not agree quite closely with its value adopted in determining the trial dead load, a new dead load is to be assumed, and the calculations are to be made afresh. The second attempt, in all probability, will give a sufficiently accurate agreement.

"*On Piers.*—To find the new value, P′, from the old value of P, the span length being unchanged, the following approximately correct equation may be used:

$$P' = P\left(0.6 + \frac{0.4}{r}\right) r_1, \qquad \text{[Eq. 21]}$$

where r and r_1, respectively, are the ratios previously indicated for elastic limits and total loads per lineal foot of span.

"In extending a curve of simple truss weights of metal per lineal foot of span beyond the limits of accurate computations, the following formulæ may either be used directly or as a check, the character of the steel, of course, being unchanged. Assume first that the live and the dead loads per lineal foot of span remain constant, and consider the effect only of longer spans and greater truss depths. Dealing first with the chords, some 85 per cent of their weights of metal per lineal foot of span vary directly as the moments of the total loads and inversely as the truss depths; but the moments vary as the squares of the span lengths, and the stresses are inversely as the truss depths. Again, the truss depths within short limits may, without serious error, be taken to vary directly as the span lengths. Such being the case, 85 per cent of the weights per foot of the chords will vary directly as the span lengths, or

$$C' = 0.15\,C + 0.85\,C\frac{l'}{l} = C\left(0.15 + 0.85\frac{l'}{l}\right), \qquad \text{[Eq. 22]}$$

where C is the chord weight per foot for the shorter span, l, and C' is the corresponding weight for the longer span, l'.

"Let W and W' be, respectively, the weights of metal per lineal foot of span in the webs of the two spans. About 75 per cent of these will vary directly as the averages of all the live-load and dead-load shears on the spans, and these average shears vary almost directly as the span lengths. Again, the said 75 per cent of W and W' will vary directly as the truss depths, and, therefore, as previously assumed, once more directly as the span lengths.

"Combining these ratios will give the equation:

$$W' = 0.25\,W + 0.75\,W\left(\frac{l'}{l}\right)^2 = W\left\{0.25 + 0.75\left(\frac{l'}{l}\right)^2\right\}. \qquad \text{[Eq. 23]}$$

But

$$T = C + W,$$

and

$$T' = C' + W' = C\left(0.15 + 0.85\frac{l'}{l}\right) + W\left\{0.25 + 0.75\left(\frac{l'}{l}\right)^2\right\}. \qquad \text{[Eq. 24]}$$

"It is well known that in trusses with parallel chords and of economic depths the weight of the chords is equal to the weight of the web; but, in trusses with polygonal chords and having centre depths less than the theoretically economic ones, as do those of all long-span bridges, the weight of the chords is much greater than that of the web. As a general average, we may assume that $C = 0.6\,T$, and $W = 0.4\,T$.

Hence

$$T' = 0.6\,T\left(0.15 + 0.85\,l'\right) + 0.4\,T\left\{0.25 + 0.75\left(\frac{l'}{l}\right)^2\right\}$$

$$= T\left\{0.19 + 0.51\frac{l'}{l} + 0.3\left(\frac{l'}{l}\right)^2\right\}. \qquad \text{[Eq. 25]}$$

"This value of T' is based on the incorrect assumption that the total loads per

lineal foot of span are the same for both spans under consideration, hence it requires a further modification, as follows:

$$T'_f = T'(0.2 + 0.8\,r_1), \qquad \text{[Eq. 26]}$$

where T'_f is the final value of the weight of truss metal per lineal foot of the longer span, and r_1 (in this case greater than unity) is the ratio of the total loads per lineal foot.

"Combining Equations 25 and 26, we have

$$T'_f = T\left\{0.19 + 0.51\frac{l'}{l} + 0.3\left(\frac{l'}{l}\right)^2\right\}(0.2 + 0.8\,r_1). \qquad \text{[Eq. 27]}$$

"A test of this formula, on carefully computed curves of truss weights for simple spans of nickel steel from 600 to 1,000 ft. in length, shows that slightly undue prominence has been given to the invariable portion of the weights, and that the following modification of the formula will give more accurate results:

$$T'_f = T\left\{0.15 + 0.55\frac{l'}{l} + 0.3\left(\frac{l'}{l}\right)^2\right\}(0.15 + 0.85\,r_1). \qquad \text{[Eq. 28]}$$

"This last formula, when tested on the truss weights of simple spans from 700 to 1,000 ft. in length for an elastic limit of 90,000 lbs., gave exceedingly close results; hence it is proper to adopt it as the equation for extension of all truss weights for simple spans, and, inferentially, for those of cantilever bridges; in fact, it has been tested on some of the actually computed truss weights of cantilever bridges and found to give excellent agreement.

"Attention is called to the semi-rational, semi-empirical character of these reduction and extension formulæ. They are, in general, the result of long personal experience in the quick computation of metal weights for bridges; but they have been modified slightly, as hereinbefore indicated, to agree with certain checks that have been made in this investigation. As far as practicable, the formulæ of Equations 20 and 28 were used for checking each other; and the results of such checks were always satisfactory. For instance, if a curve of truss weights for one class of steel were used as a basis for finding, by Equation 20, the corresponding curve for another class of steel, the latter curve would be checked by starting from any desired point (generally where the weights of actually computed bridges cease) and passing, by using Equation 28, from one span length to another, 100 or 200 ft. greater, and continuing in this manner to the superior end of the curve."

The reader who is interested not only in the weights of metal for bridges but also in the economics of structures built of various alloys of steel, is advised to read the paper on "The Possibilities in Bridge Construction by the Use of High Alloy Steels," from which several of the preceding pages have been copied. It was published in the *Transactions* of the American Society of Civil Engineers, Vol. LXXVIII, page 1 (1915).

Illustrative Examples

In order to demonstrate how to use the various diagrams of weights of metal given in this chapter, certain characteristic examples with their solutions will now be presented. The numerical values are generally carried out only to that degree of accuracy which good engineering warrants, and as indicated in Table 58*a*.

A. What weight of metal per lineal foot would be required for a single-

track, deck, plate-girder bridge of 90 feet span to carry a Class 55 live load?

Turning to Fig. 55*b*, we find the intersection of a vertical line through 90 on the bottom line with the inclined line for Class 55, and pass from it horizontally to the extreme right vertical where the reading gives 1430. It must be remembered that the effective length from centre to centre of bearings is about 87.5 feet instead of 90 feet.

B. What is the total weight of steel per lineal foot in a single-track, through, riveted, Pratt-truss span of 182 feet to carry a Class 65 live load; and how is it distributed between the different portions of the structure?

Turning to Figs. 55*d*, 55*e*, 55*g*, and 55*h*, we find the following:

Fig. 55*d* indicates for the weight of the Lateral System 220 pounds, and for that On Piers 130 pounds.

Assume that there are seven panels of 26 feet each, then Fig. 55*e* gives for the weight of Floor System 650 + 10 = 660 pounds.

Fig. 55*g* shows for parallel chords a truss weight of 1,680 pounds.

The sum of these weights is 2,690 pounds.

As a check, Fig. 55*h* gives for the total weight of metal per lineal foot 2,700 pounds. An exact coincidence is impracticable to obtain except accidentally, owing to the slight errors involved in reading the quantities indicated by the various intersecting lines on the several diagrams, and because of a possible slight difference in the weight of the floor system due to variation in panel length.

C. What is the total weight of metal in a single-track, deck, riveted Pratt-truss span, 270 feet long, in nine equal panels, and having a width of 18 feet between central planes of trusses, the live load being Class 40; and how is the said weight divided?

Fig. 55*m* shows that the total weight of metal per lineal foot of span is 2,990 pounds.

Fig. 55*l* indicates that 2,030 pounds of this are contained in the trusses.

From Fig. 55*j* the weight for the floor system is found thus: At the lower left-hand corner the horizontal line for a 30-foot panel is followed over to the 18-foot width-curve; the vertical through the intersection is traced upward to the Class 40 line, and the horizontal through this intersection, carried to the left vertical, indicates that the weight is 530 pounds.

Fig. 55*k* gives the weight of the metal on piers as 80 pounds, and that of the lateral system as 380 pounds; and it also shows that the best truss depth is 38 feet and that the proper perpendicular distance between central planes of trusses is 18 feet, as was assumed.

The sum of the last four weights is 3,020 pounds, checking that first found within thirty pounds, which is close enough.

D. What are the various metal weights for a double-track-railway, through, pin-connected, Petit-truss bridge of 720 feet span designed for Class 70 loading?

From Fig. 55*dd* the total metal in span is found to be 19,000 pounds, and the weight of metal in the trusses 16,100 pounds.

Fig. 55*cc* indicates 1,770 pounds for the floor system, 800 pounds for the lateral system, and 320 pounds for the metal on piers.

The sum of the last four weights is 18,990 pounds, which varies from the total first found by only one-twentieth of one per cent.

E. What are the various weights of metal in a single-track, pin-connected, centre-bearing swing-span 440 feet long, to carry a Class 55 live load?

The weight of the floor system is the same as that for a similar fixed span in which the perpendicular distance between central planes of trusses is the same. In this case the distance will be the minimum allowable, or about 17.5 feet. Assume the panel length for each arm to be 26.4 feet and that at the tower 17.5 feet. Fig. 55*n* gives the weight as 640 pounds.

For the laterals we must use Fig. 55*d* and a span length of $0.7 \times 440 = 308$ feet, which gives the weight as 310 pounds.

For the truss weight we must use Fig. 55*o* and a span length of $0.6 \times 440 = 264$ feet. This indicates a weight of 2,130 pounds.

The sum of these three weights is 3,080 pounds, and to this must be added about 30 per cent for the drum, machinery, and metal on piers, making 4,010 pounds for the total weight of metal.

As a rough check on this, Fig. 55*ee* gives 78.5 per cent as the figure to apply to the total weight of metal for a 440-foot fixed span, which weight Fig. 55*q* shows to be 5,270 pounds. $78.5 \times 5,270 = 4,140$ pounds, indicating a difference of 130 pounds or about three per cent. This check, at first thought, may not be deemed sufficiently accurate, but it must be remembered that, as a matter of precaution, in order to provide for the individual idiosyncrasies of bridge designers and to be on the safe side, the percentages in Fig. 55*ee* have been kept somewhat high. Again, it must not be forgotten that the methods herein suggested for finding the weights of swing spans are not claimed to be as accurate as those given for finding the weights of fixed spans.

F. What are the economic functions and weights of metal for a single-track railway trestle 200 feet high with a batter of an inch and a half to the foot, to carry a Class 55 live load? It is assumed that there are no restrictions as to the lengths of bays and that alternate spans are tower spans.

From Fig. 55*oo* it is seen that the best length for the intermediate spans is 86 feet, and that the length for the tower span is given as 52.5 feet. Actually the lengths chosen would probably be 85 and 50 feet, and the variation in weight caused by such a departure from exact economics would be very small. For this economic layout we have the following weights, taken from Figs. 55*nn* to 55*qq*, inclusive.

Girders

See Fig. 55*nn*

85′ at 1,125 lbs. = 95,630 lbs.
50′ at 640 lbs. = 32,000 lbs.

135′ = 127,630 lbs. Average weight = 945 lbs.

Girder Bracing

See Fig. 55*nn*

85′ at 107 lbs. = 9,100 lbs
50′ at 50 lbs. = 2,500 lbs

135′ = 11,600 lbs. Average weight = 86 lbs.

Longitudinal Bracing

See Fig. 55*pp*

555 × 200 ÷ 135 = 822 lbs.

Transverse Bracing

See Fig. 55*pp*

412 × 200 ÷ 135 = 610 lbs.

Columns

See Fig. 55*qq*

852 × 200 ÷ 135 = 1,262 lbs.

Total = 3,725 lbs.

As a check on this, Fig. 55*rr* gives a total weight per lineal foot of 3,670 lbs.

G. If in the last example it had been necessary to make the tower spans 40 feet long and the intermediate spans 60 feet long, what would have been the various weights of metal?

Using the same diagrams we have the following:

Girders

See Fig. 55*nn*

60′ at 770 lbs. = 46,200 lbs.
40′ at 530 lbs. = 21,200 lbs.

100′ = 67,400 lbs. Average weight = 674 lbs.

Girder Bracing

See Fig. 55*nn*

60′ at 60 lbs. = 3,600 lbs.
40′ at 40 lbs. = 1,600 lbs.

100′ = 5,200 lbs. Average weight = 52 lbs.

Longitudinal Bracing

See Fig. 55*pp*

555 × 200 ÷ 100............1,110 lbs.

Transverse Bracing

See Fig. 55*pp*

412 × 200 ÷ 100........... 824 lbs.

Columns

See Fig. 55*qq*

658 × 200 ÷ 100.............1,316 lbs.

Total..................3,976 lbs.

This indicates an excess of metal equal to about seven per cent, due to the uneconomic layout; but there would be some saving in the longitudinal bracing that would reduce the excess to about five per cent.

H. A single-track-railway trestle 60′ high is laid out with towers 30′ long and two intermediate solitary bents between adjacent towers, the batter of columns being one and a half inches to the foot. It is to carry a Class 70 loading. What are the economics and the weights of metal?

From Fig. 55*zz* the best length of the intermediate span is seen to be about 40 feet.

The weights are determined as follows:

Girders

See Fig. 55*tt*

Average weight per foot.................... 575 lbs.

Girder Bracing

See Fig. 55*tt*

Average weight per foot.................... 40 lbs.

Towers and Bents

See Fig. 55*yy*

Average weight per foot for 40-foot intermediate spans........................ 925 lbs.

Total............................ 1,540 lbs.

Fig. 55*zz* makes this total 1,540 lbs., which checks exactly.

I. If in Case F the trestle had carried a double track, what would have been the various weights of metal?

Applying the rules given, we find the following:

Girders and bracing, 2 × 991	1,982 lbs.
Longitudinal bracing, 630 × 1.8	1,134 lbs.
Transverse bracing, 640 × 1.7	1,088 lbs.
Columns, 1,275 × 1.6	2,040 lbs.
Total	6,234 lbs.

J. What are the economic functions and the weights of metal for a single-track, electric-railway trestle, Type I, 150 feet high with columns battered two inches to the foot transversely, to carry Class 30 live load, the structure being on a four-degree curve, and the minimum allowable thickness of metal being $\frac{5}{16}''$?

In order to select the economic lengths of spans, it will be necessary to determine the steam railway live load to which Class 30 corresponds. Using Class 40 of the steam railway live loads as a basis, and assuming an 80-foot loaded length, we have the following:

Class 30 Electric Railway

Live load (Fig. 6*h*)	2,230 lbs. per lin. ft.
Impact (Fig. 7*d*) — 47 per cent	1,050 lbs. per lin. ft.
Total L.L. + I.L.	3,280 lbs. per lin. ft.

Class 40 Steam Railway

Live load (Fig. 6*d*)	5,460 lbs. per lin. ft.
Impact (Fig. 7*c*) — 71.7 per cent	3,920 lbs. per lin. ft.
Total L.L. + I.L.	9,380 lbs. per lin. ft.

$$\therefore r = \frac{3280}{9380} = 0.35.$$

Class 30 electric railway therefore corresponds to Class 40 × 0.35 = Class 14 steam railway.

Turning now to Fig. 55*oo*, we find the proper length of tower span to be about 62 feet, while that of the intermediate span, for a Class 14 loading, is 102 feet. We shall adopt 60 feet for the tower span and 100 feet for the intermediate span. The erection of a span longer than the latter would be a rather difficult proceeding, or at least uneconomic. This makes the distance from centre to centre of towers 160 feet.

We then proceed to find the weights of the various portions in the following manner:

Girders and Girder Spanning

100′ Span

Live load Class 30, 100′ span (Fig. 6*h*)	2,170 lbs. per lin. ft.
Impact, 44 per cent (Fig. 7*d*)	960 lbs. per lin. ft.
Dead load,	
Deck	400 lbs. per lin. ft.
Girders and brac. (Fig. 55*nn*) 680 + 110 =	790 lbs. per lin. ft.
Total	4,320 lbs. per lin. ft.

or 2,160 lbs. per lin. ft. per girder.

Weight of girders (Fig. 55*ff*) is 2 × 320...... 640 lbs. per lin. ft.

As the weight assumed in finding the load on the girder was 680 pounds, this result is satisfactory.

Weight of girder bracing (Fig. 55*nn*) = 120 × 0.8.............................. 96 lbs. per lin. ft.

Total weight of girders and bracing.......... 736 lbs. per lin. ft.

60′ Span

Live load, Class 30, 60′ span (Fig. 6*h*)....... 2,550 lbs. per lin. ft.

Impact, 51 per cent (Fig. 7*d*)............... 1,300 lbs. per lin. ft.

Dead load,

Deck............................... 400 lbs. per lin. ft.

Girders and bracing (Fig. 55*nn*) = 450 + 60......................... 510 lbs. per lin. ft.

Total........................... 4,760 lbs. per lin. ft.

or 2,380 lbs. per lin. ft. per girder.

Weight of girders (Fig. 55*ff*) = 2 × 200..... 400 lbs. per lin. ft.

As the weight assumed in finding the load on the girder was 450 pounds, this result is satisfactory.

Weight of girder bracing (Fig. 55*nn*) = 60 × 0.8.............................. 48 lbs. per lin. ft.

Total weight of girders and bracing......... 448 lbs. per lin. ft.

Average weight per lineal foot of

$$\text{structure} = \frac{(100 \times 736) + (60 \times 448)}{160} = \quad 628 \text{ lbs. per lin ft..}$$

Transverse Bracing of Towers

See Fig. 55*pp*

$420 \times \frac{150}{160} \times 0.8$......................... 315 lbs. per lin. ft.

Longitudinal Bracing of Towers

See Fig. 55*pp*

$580 \times \frac{150}{160} \times 0.8$......................... 435 lbs. per lin. ft.

Columns of Towers

See Fig. 55*qq*

Class 40 railway loading gives 700 lbs. per vert. ft. (Fig. 55*qq*).

Class 30; $C_E = 700\ (0.2 + 0.8 \times 0.35) = 336$ lbs. per vert. ft.

$336 \times \frac{150}{160}$............................ 315 lbs. per lin. ft.

Total metal in structure on tangent...... 1,693 lbs. per lin. ft.

Add for effect of 4 degree curve 1,693 × .08.. 135 lbs. per lin. ft.

Total metal in structure................ 1,828 lbs. per lin. ft.

K. A 400-foot, riveted, Petit-truss span carries the following loads:

First. A double-track steam railway of Class 60 inside of the trusses.

Second. A single-track electric railway (Class 25) and wagons upon a 12-foot clear roadway paved with creosoted blocks, resting upon six inches of reinforced concrete, on each side outside of the trusses, and a six-foot sidewalk (Class C live loading) of four-inch granitoid outside of each wagon-way. What is the weight of metal per lineal foot for the trusses?

The live loads per lineal foot for one truss are as follows:

Railway loading..................	6,800 lbs.	(From Fig. 6*e*)
Impact due to the same, 17 per cent	1,156 lbs.	(From Fig. 7*c*)
Electric railway loading...........	1,810 lbs.	(From Fig. 6*k*)
Impact due to the same, 12½ per cent.	227 lbs.	(From Fig. 7*d*)
Sidewalk loading, 6 × 49...........	294 lbs.	(From Fig. 6*o*)
Impact from same, 10 per cent......	29 lbs.	(From Fig. 7*e*)
Summation...................	10,316 lbs.	

The approximate dead load per lineal foot per truss will be as follows:

Railway floor.....................	500 lbs.
Pavement and base, 12 × 90	1,080 lbs.
Sidewalk, 6 × 50..................	300 lbs.
Girder rails, 2 × 30	60 lbs.
Handrail	40 lbs.
Railway floor system (Fig. 55*x*)......	700 lbs.
Highway floor system, say..........	600 lbs.
Lateral system, say................	300 lbs.
Truss, assumed....................	6,000 lbs.
Total dead load................	9,580 lbs.
Total live and impact loads.....	10,316 lbs.
Total......................	19,896 lbs.

Call this temporarily 20,000 lbs.

Referring to Fig. 55*hh*, we find for a total load of 20,000 lbs. and a span of 400 feet a weight of about 4,900 lbs., which shows that the truss weight assumed was too high. Assuming a new truss weight of 4,600 lbs. would make the new total load 18,496 lbs., for which the diagram makes the weight 4,550 lbs. This checks closely, hence the weight for the two trusses would be 2 × 4,550 = 9,100 lbs.

As the diagrams for cantilevers are employed in exactly the same manner as are those for simple spans, there is no need for providing an example of the method of their utilization.

CHAPTER LVI

QUANTITIES FOR PIERS, PEDESTALS, ABUTMENTS, RETAINING WALLS, AND REINFORCED CONCRETE BRIDGES

MANY of the tables and diagrams given in this chapter have been prepared from time to time during the last three decades of the author's practice in order to facilitate the calculation of quantities of materials in substructure and masonry work. They have been found so convenient that it has been deemed worth while to reproduce them here for the benefit of bridge engineers in general, and to add to them materially so as to cover, to as great an extent as practicable, all lines of bridgework, including reinforced concrete construction.

PIERS

In Fig. 56*a* are given the volumes of copings and of shafts of piers with vertical sides. The curves thereof are of little value for the shafts of ordinary piers, as these are generally battered. For solid circular pivot-piers, as well as for any coping, the curves can be used advantageously. To apply the diagram for the vertical shaft of any pier or any coping, it is necessary to enter at the lower margin with the width of the shaft or coping in feet, trace vertically to the curve for the length of the tangent portion, and pass horizontally to the right or left margin, where will be indicated the volume for one foot of height. This quantity multiplied by the height will give the total volume in the pier-shaft or coping. It will be noted that the lower curve, for which the length of the tangent portion of the shaft is zero, applies directly to circular piers.

Figs. 56*b*, 56*c*, 56*e*, 56*f*, 56*h*, and 56*i* give the volumes in cubic yards of the truncated cones formed by bringing together the rounded ends of battered piers. They are for batters of one-half, three-quarters, and one inch to the foot, which are those generally used in pier designing. Figs. 56*d*, 56*g*, and 56*j* give the volumes in cubic yards for one-foot-wide strips of pier between the rounded ends for batters of one-half, three-quarters, and one inch to the foot.

To find the total volume of any pier, add together that of the coping, that of the two rounded ends which form a truncated cone, and the product of the volume of a one-foot strip by the length of the portion of the pier between the vertical axes of the rounded ends.

Pedestals

In Figs. 56*k*, 56*l*, and 56*m* are given the volumes of the shafts of concrete pedestals, up to heights of twenty feet, for tops from 2.5 to 5.5 feet square. Each of these diagrams covers all standard batters from one inch

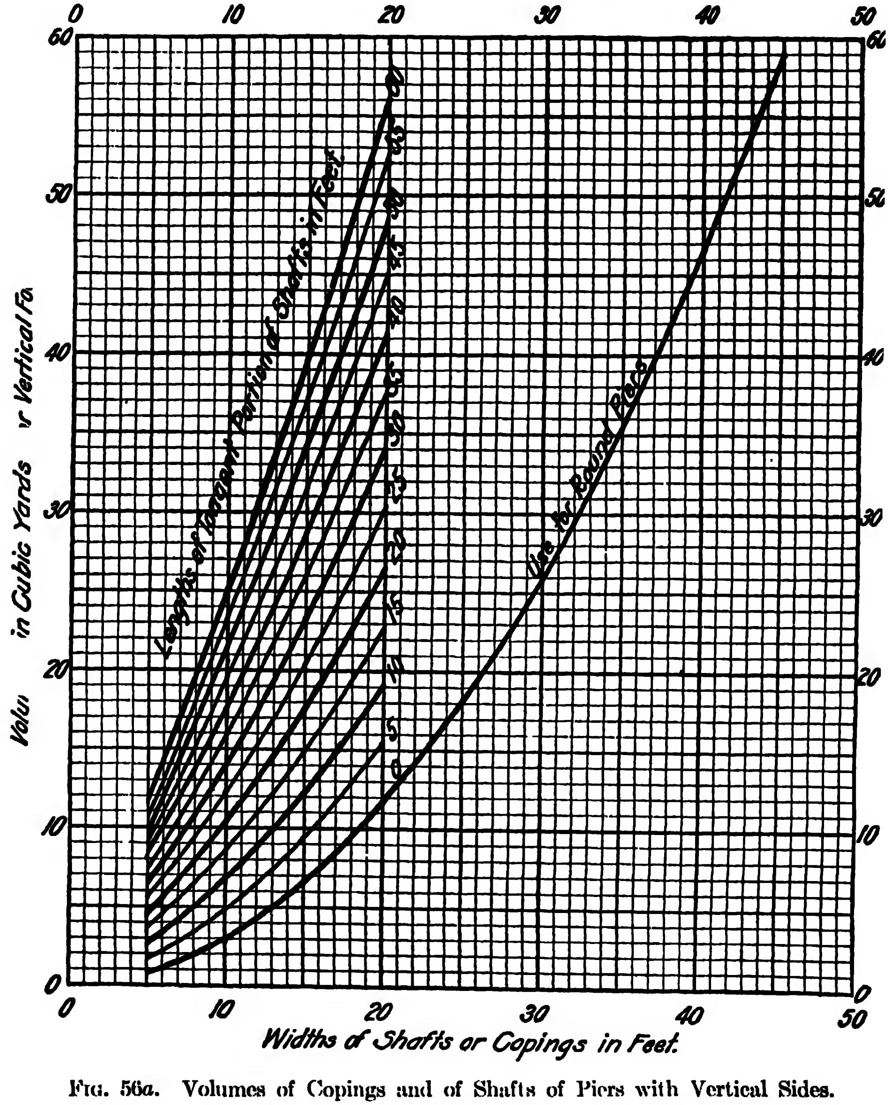


Fig. 56*a*. Volumes of Copings and of Shafts of Piers with Vertical Sides.

to six inches per foot, varying by half inches. As it is not customary today to put copings on concrete pedestals, the total volume for the shaft of any pedestal can be taken directly from one of these diagrams. Should any intermediate batter be employed, which is unlikely, the approximately

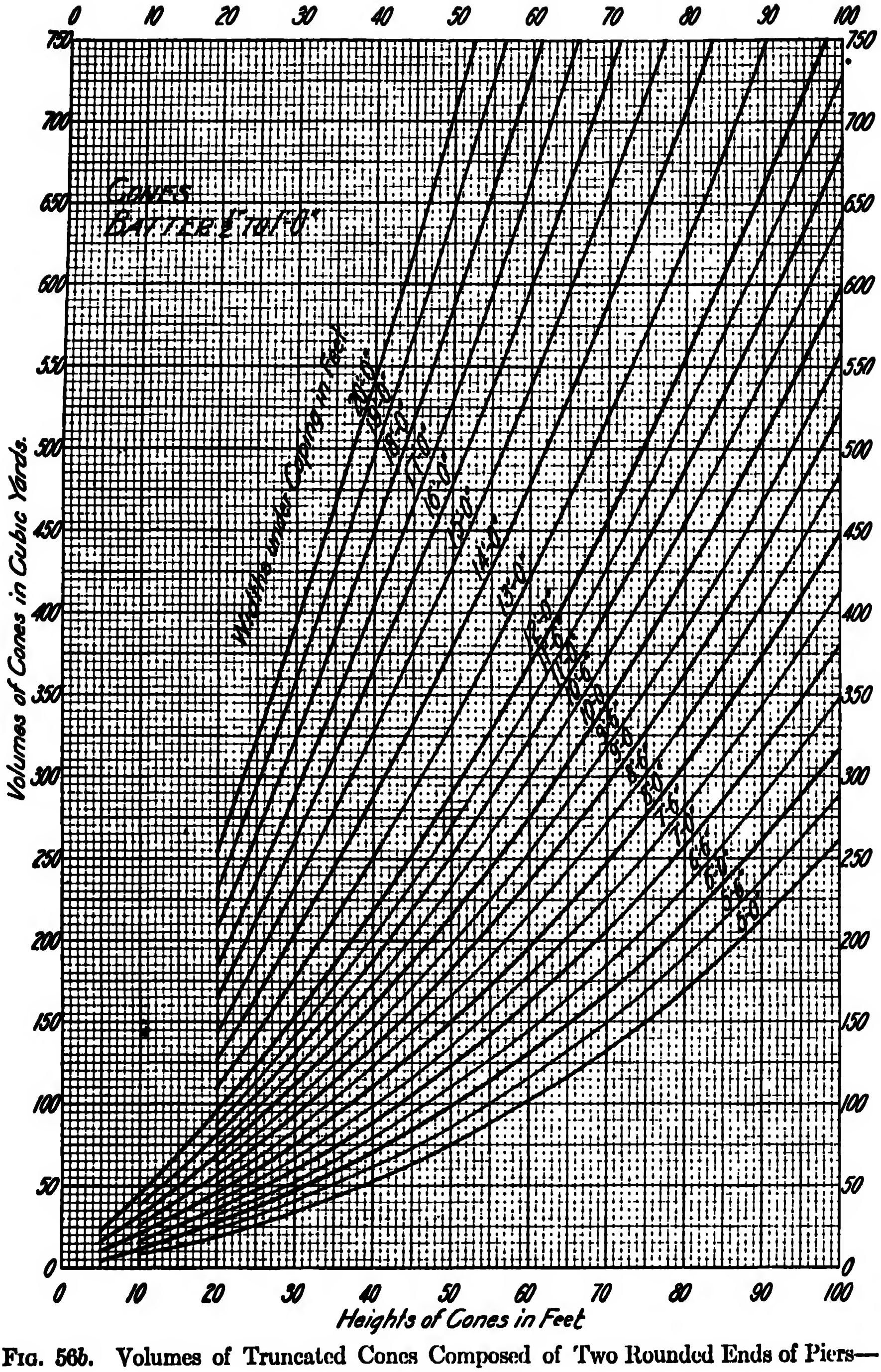


FIG. 56b. Volumes of Truncated Cones Composed of Two Rounded Ends of Piers—Batter ½" to 1′ 0″.

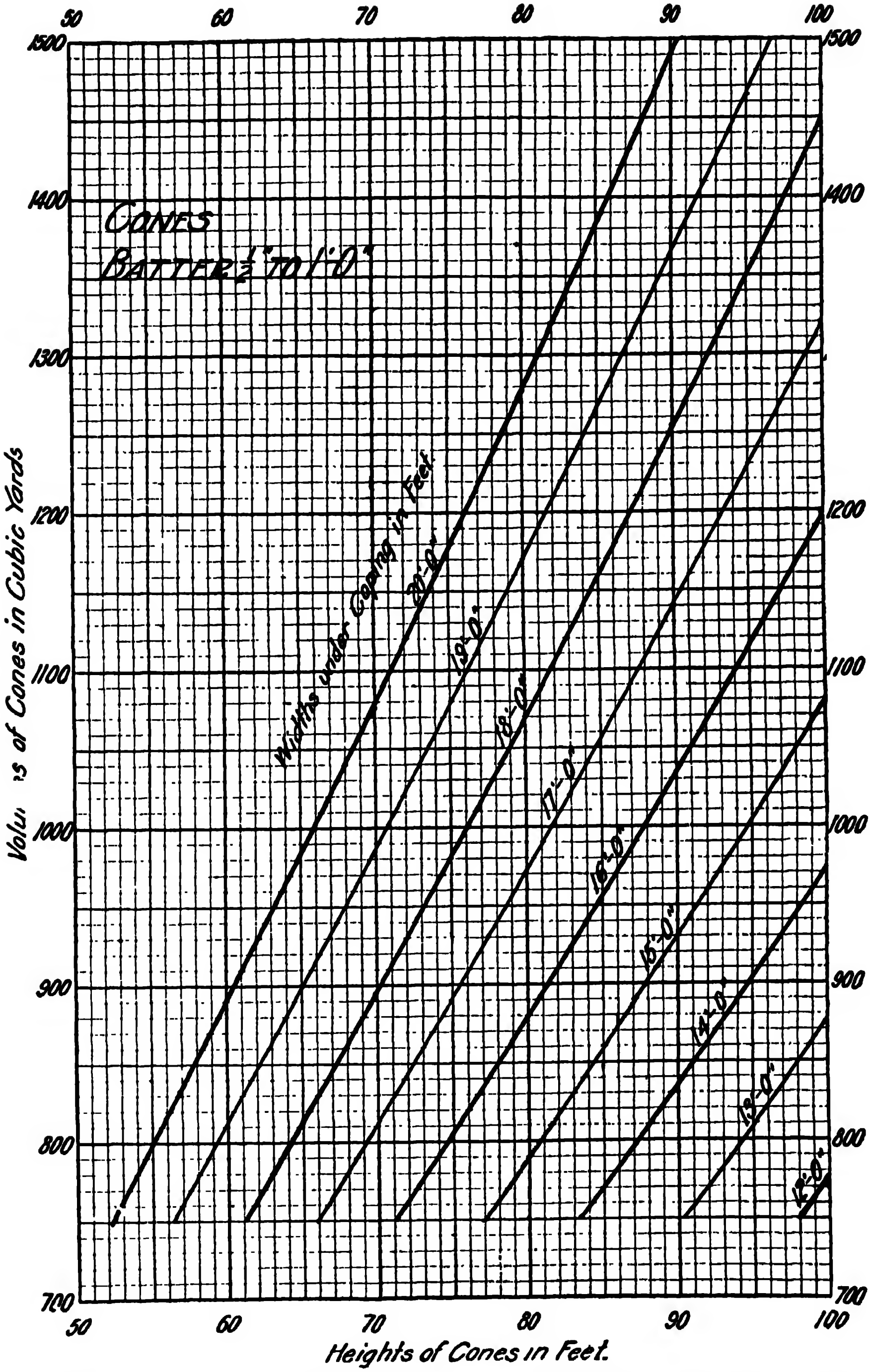


Fig. 56c. Volumes of Truncated Cones Composed of Two Rounded Ends of Piers—Batter ½" to 1' 0".

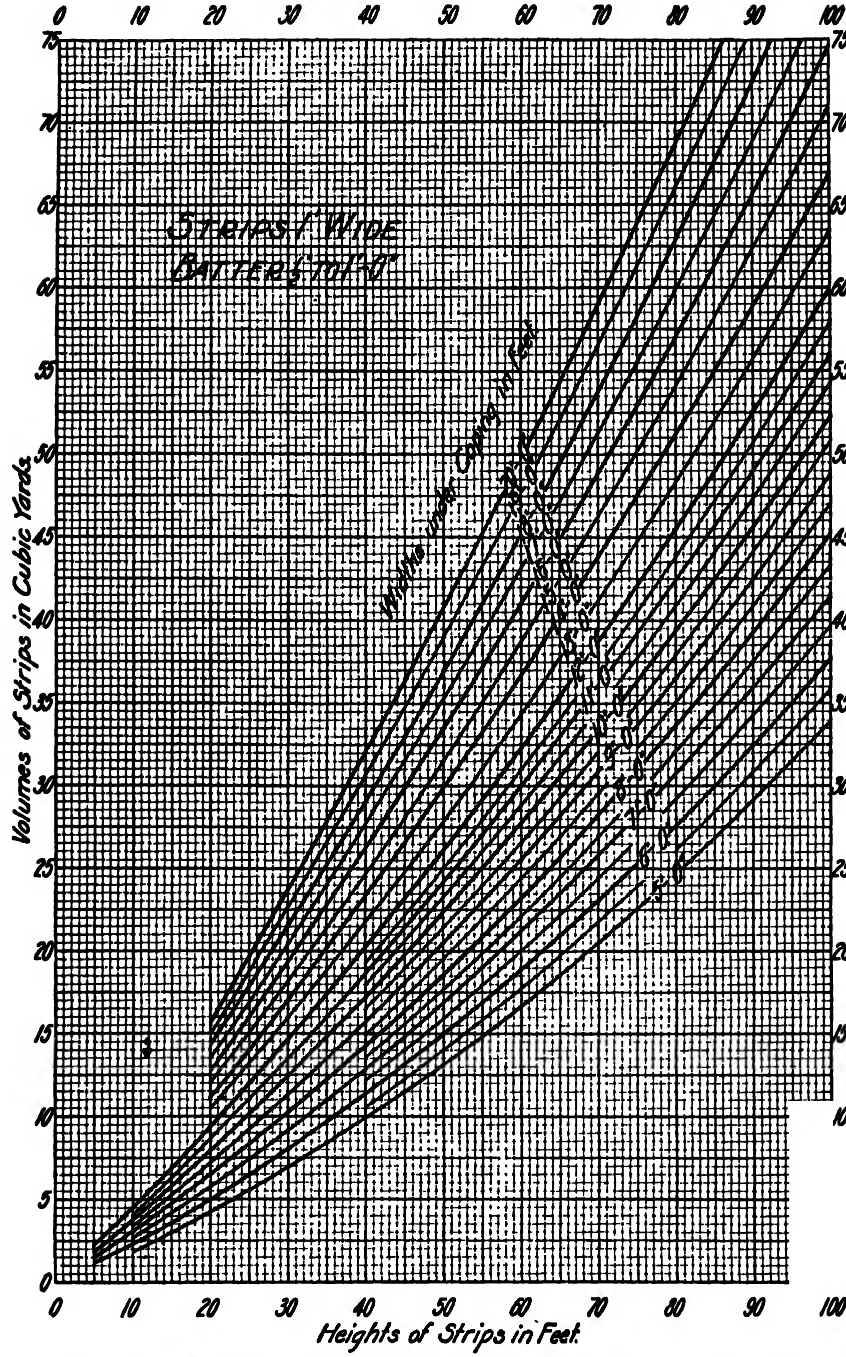


Fig. 56d. Volumes of Strips One Foot Wide in Middle Portion of Round-Ended Piers—Batter ½" to 1' 0".

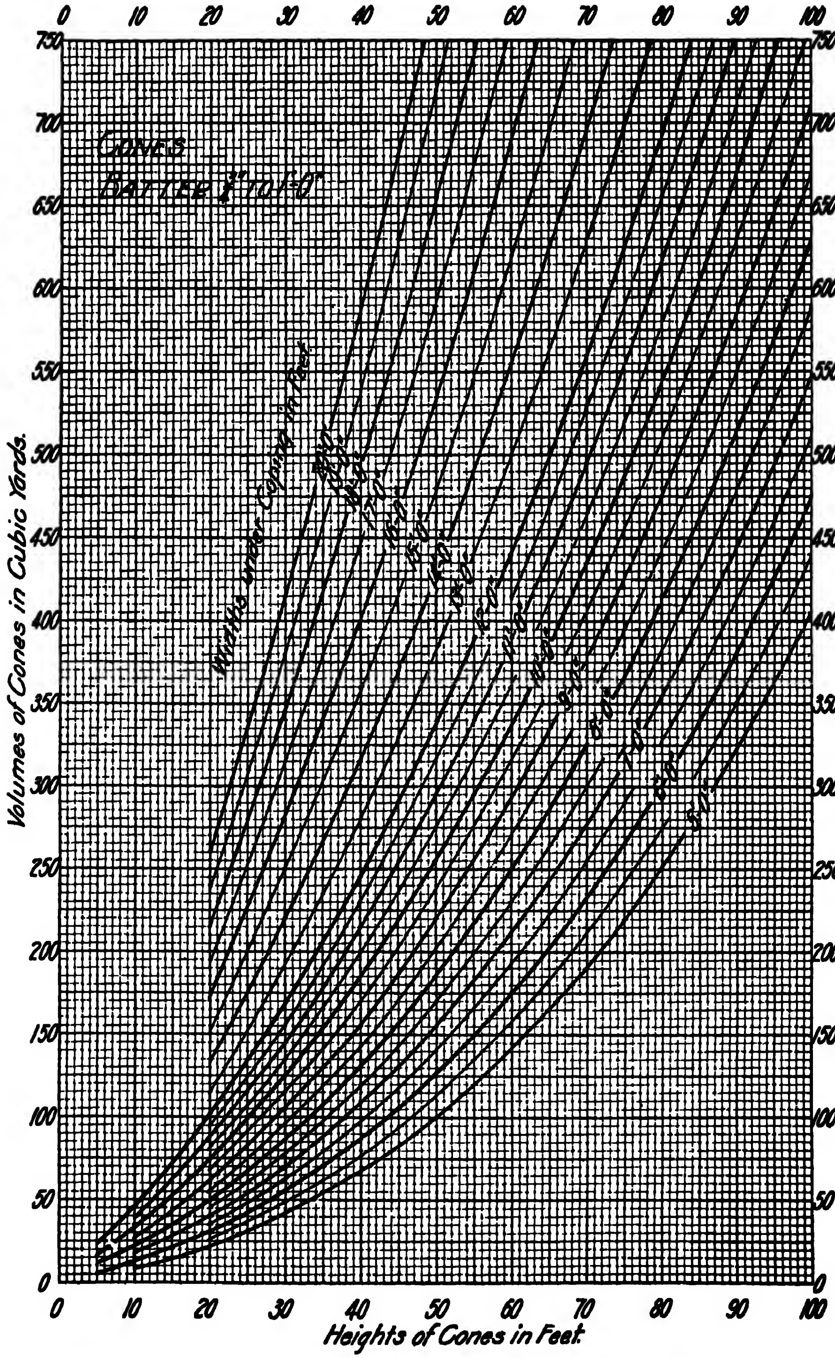


Fig. 56e. Volumes of Truncated Cones Composed of Two Rounded Ends of Piers—Batter ¾" to 1' 0".

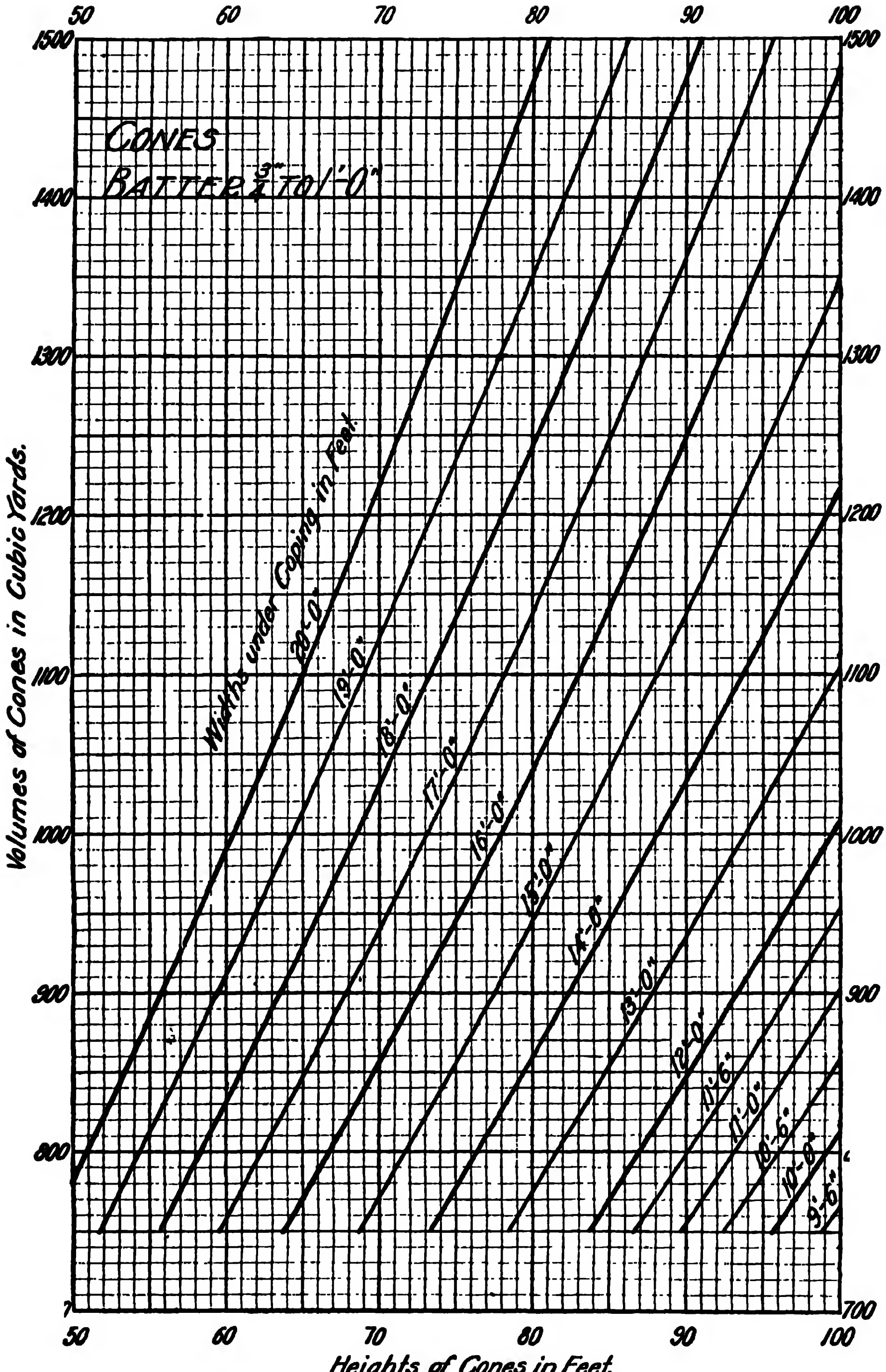


Fig. 56f. Volumes of Truncated Cones Composed of Two Rounded Ends of Piers—Batter ¾" to 1' 0".

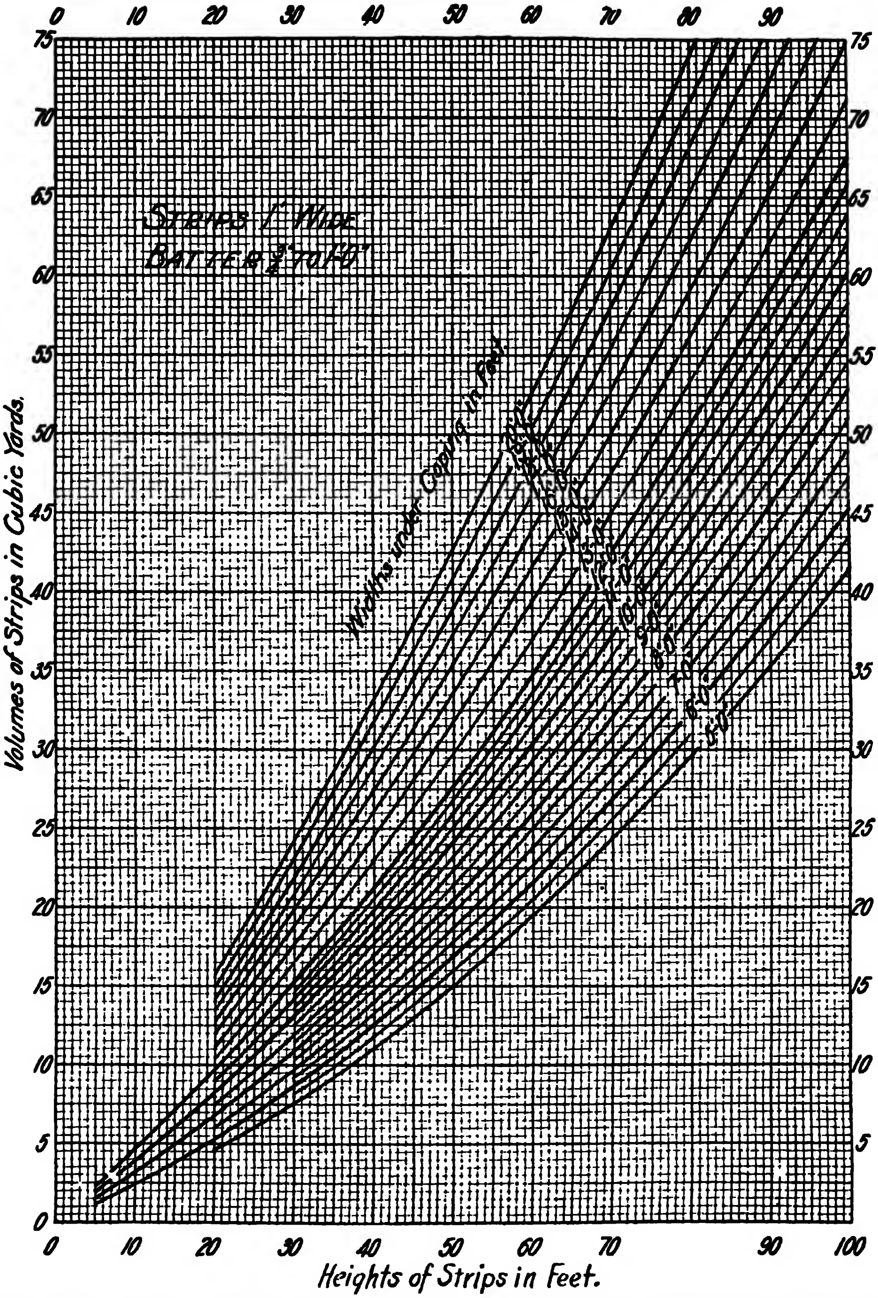


Fig. 56g. Volumes of Strips One Foot Wide in Middle Portion of Round-Ended Piers—Batter $\frac{3}{4}''$ to $1'\ 0''$

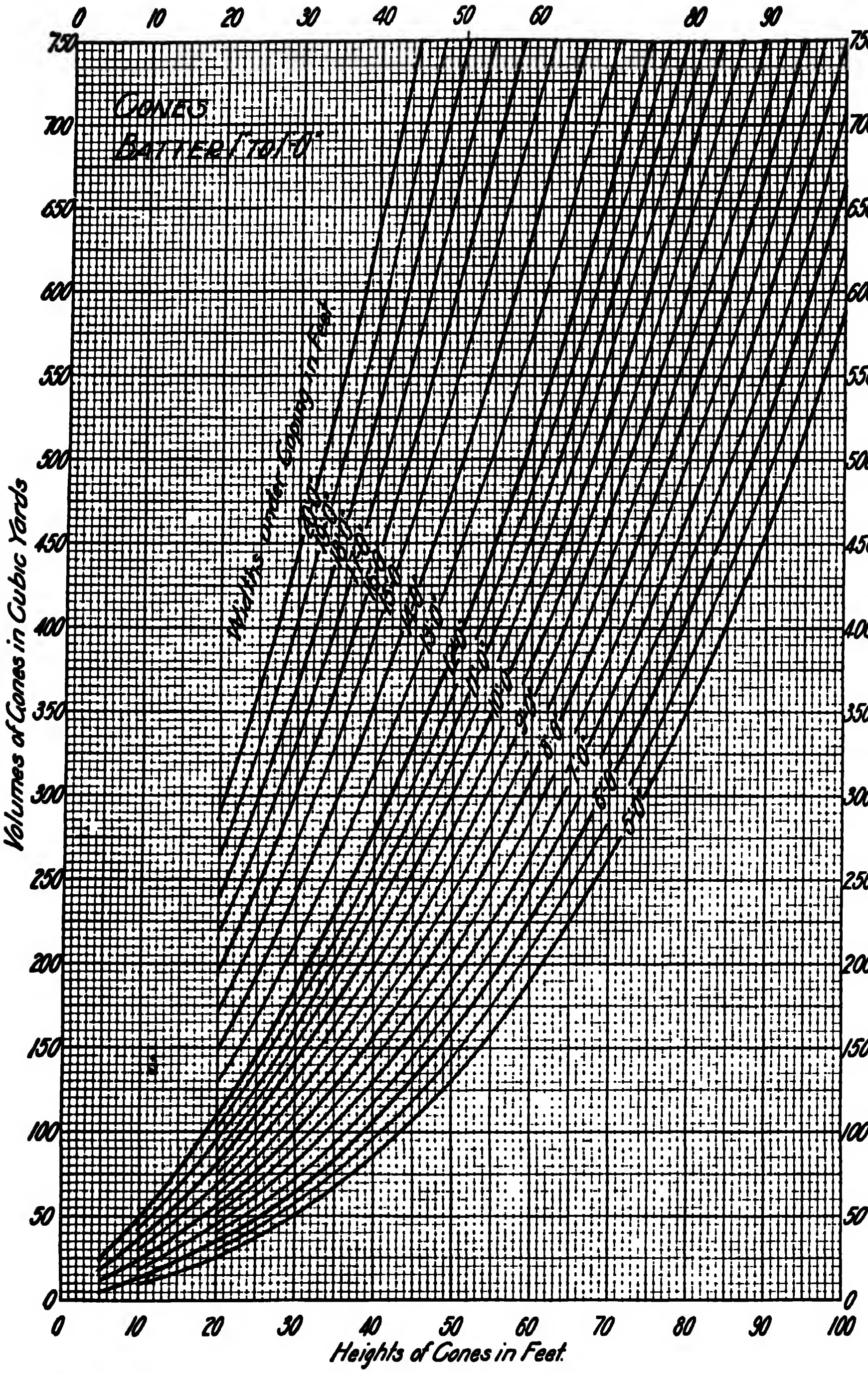


Fig. 56h. Volumes of Truncated Cones Composed of Two Rounded Ends of Piers—Batter 1″ to 1′ 0″.

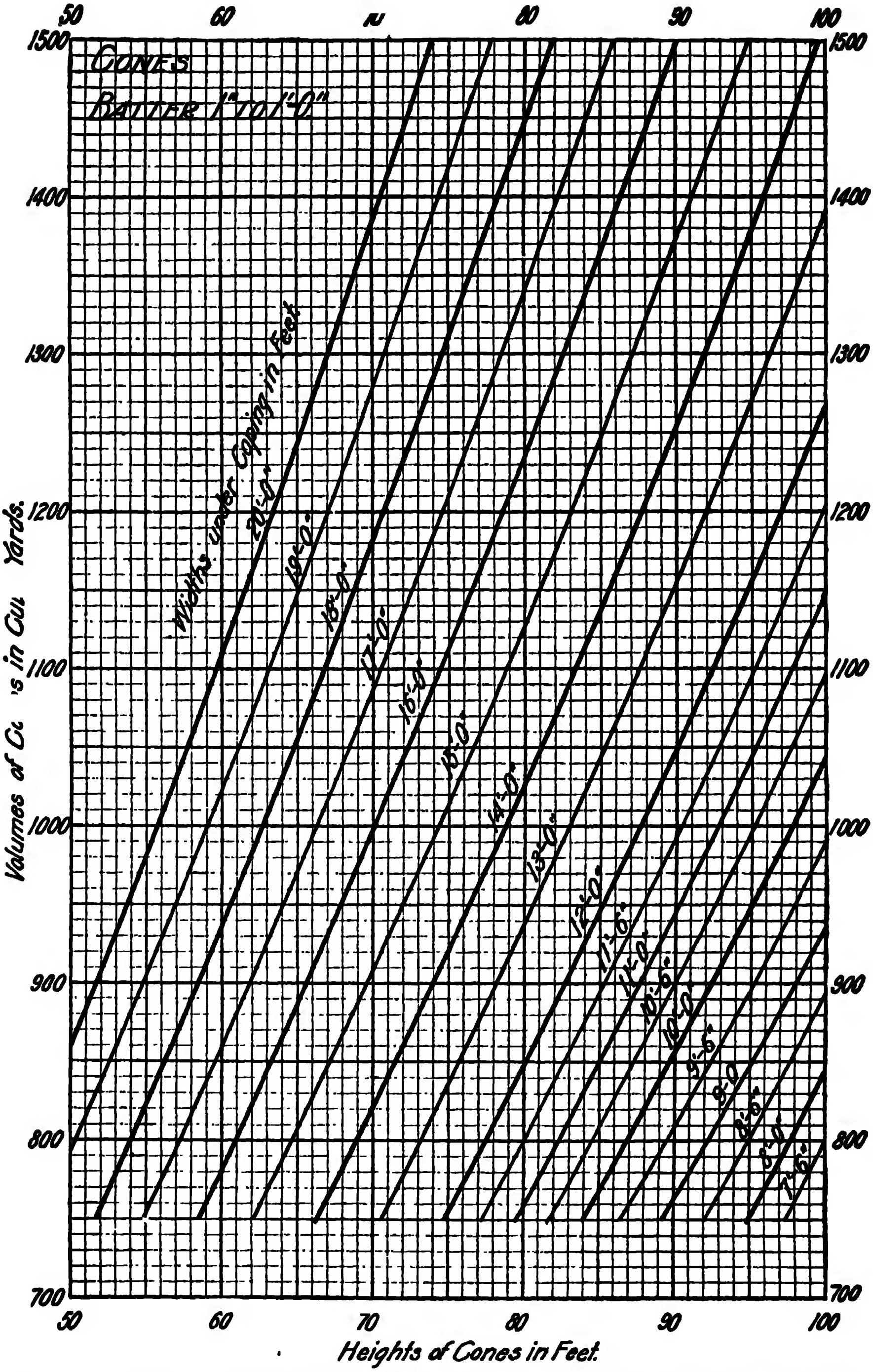


Fig. 56*i*. Volumes of Truncated Cones Composed of Two Rounded Ends of Piers—Batter 1″ to 1′ 0″.

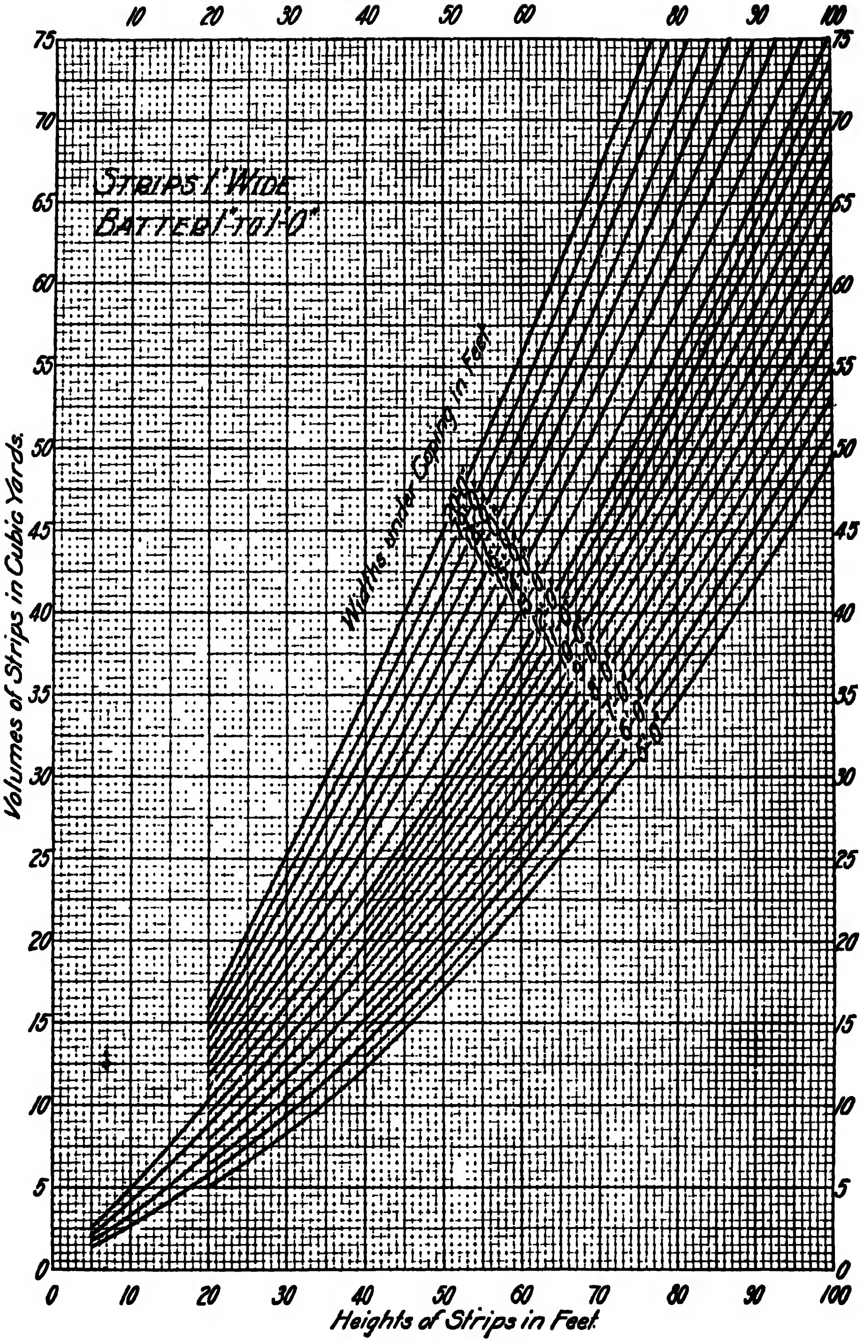


Fig. 56j. Volumes of Strips One Foot Wide in Middle Portions of Round-Ended Piers—Batter 1″ to 1′ 0″.

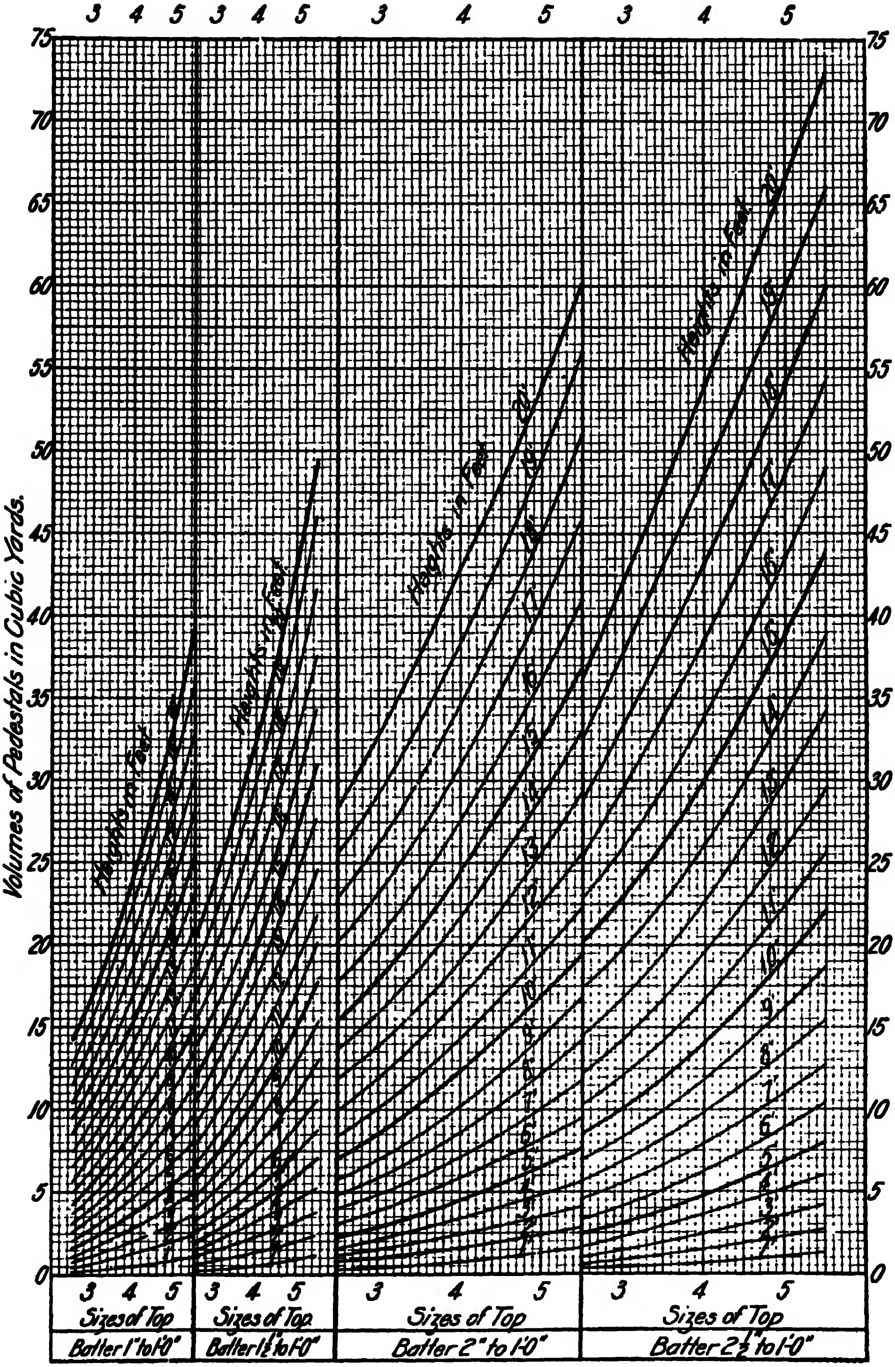


FIG. 56k. Volumes of Pedestals.

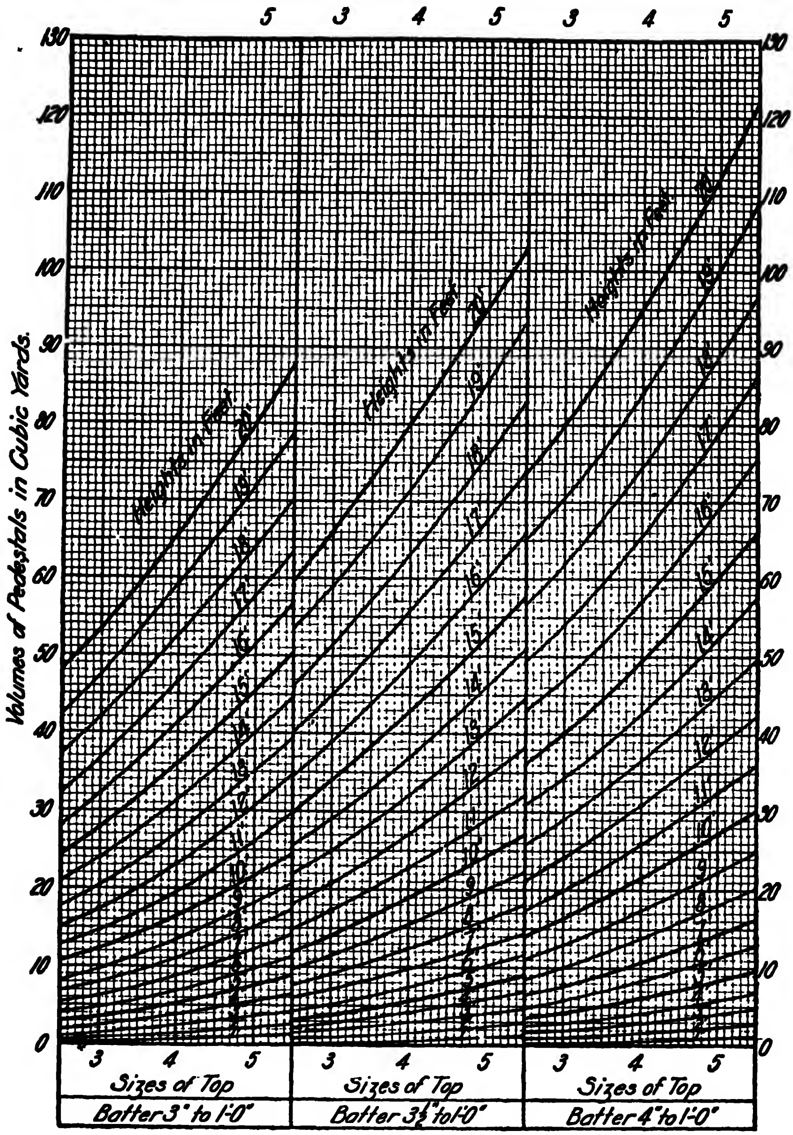


FIG. 56*l*. Volumes of Pedestals.

correct volume can be obtained by direct interpolation. If there is to be an offset base, the figuring of the additional volume therefor will not require more than a minute or two.

ABUTMENTS

The following method will give, with very little calculation, the volume of concrete or masonry in any wing-abutment for a single-track railway bridge. In Fig. 56*n* is presented a drawing of the type of abutment

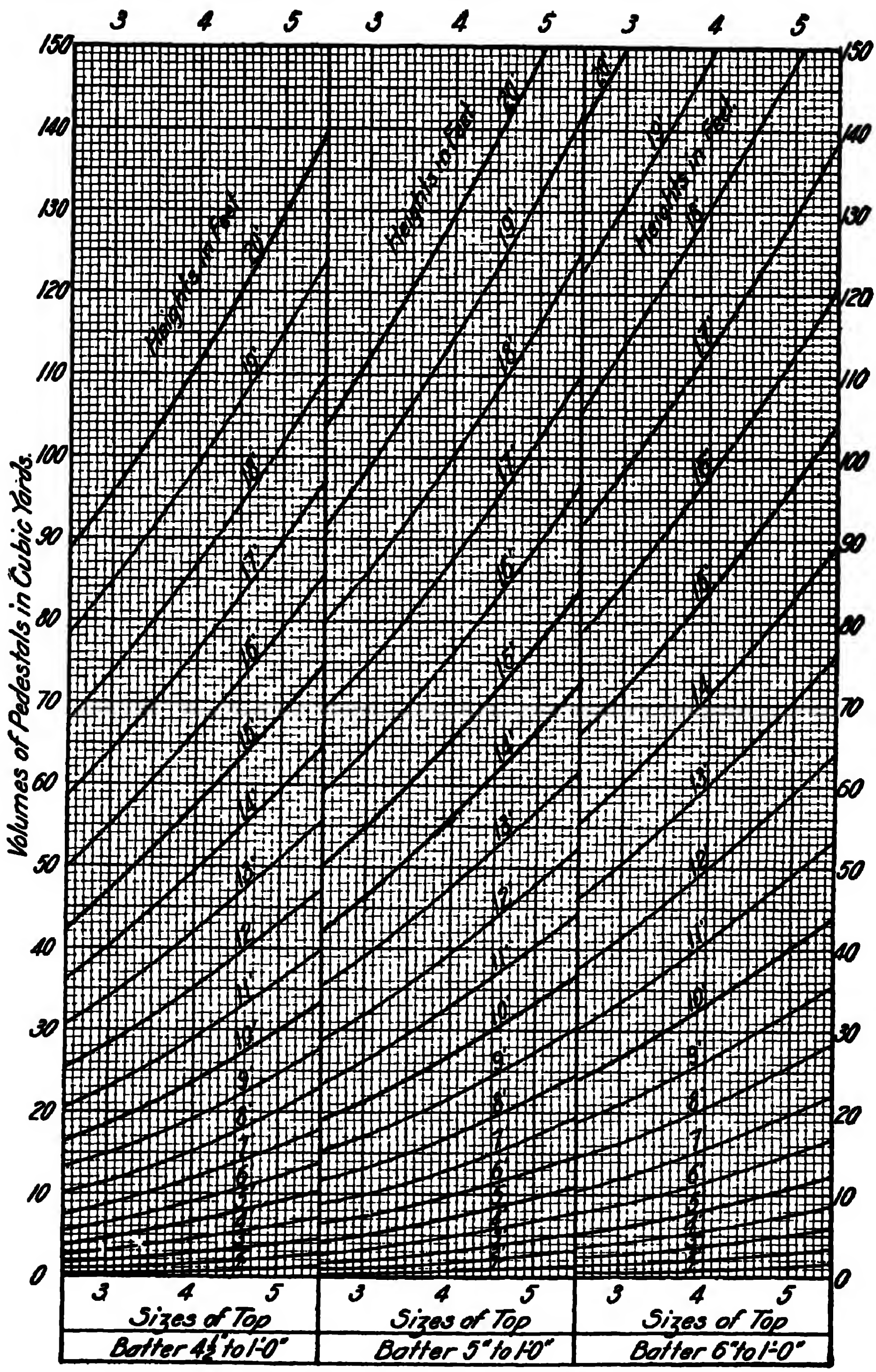


FIG. 56m. Volumes of Pedestals.

used in preparing the curves of Figs. 56*o*, 56*p*, and 56*q*. From the lower set of curves in Fig. 56*o* can be obtained the total combined volume of parapet, coping, and shaft of that portion of the standard single-track abutment included between the vertical planes *A B* at the ends of the parapet wall. The upper set of curves in this figure gives the volume for that portion of two symmetrical wing-walls extending beyond the planes *A B*. If the

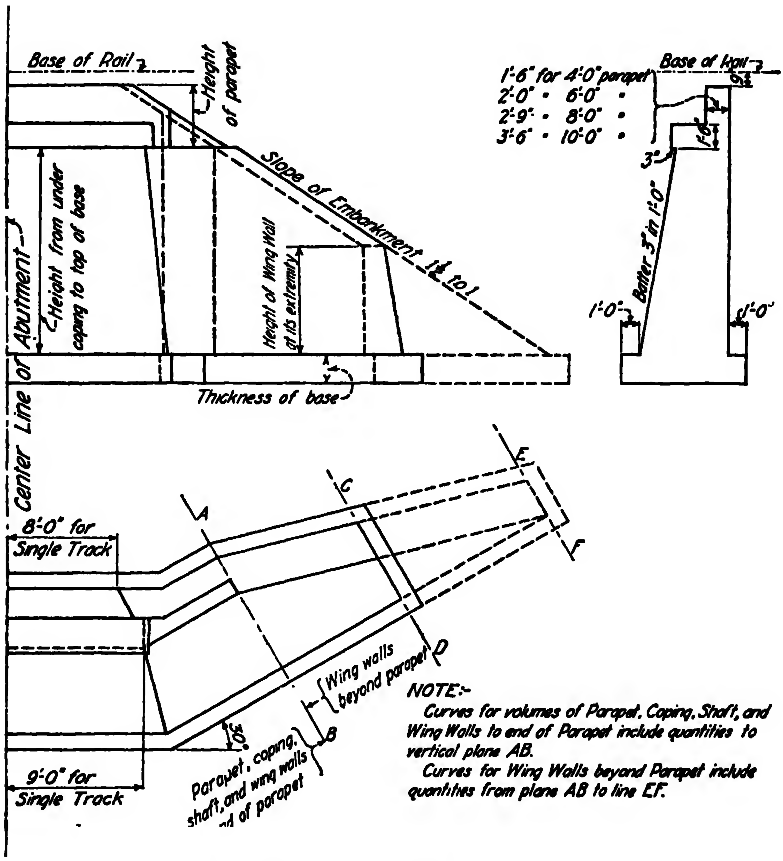


FIG. 56*n*. Typical Wing Abutment.

wing-walls terminate before the top slope intersects the base, a deduction is to be made in accordance with the note at the top of the figure. In case the two wing-walls are not symmetrical with respect to the bridge tangent, each wall can be treated separately by dividing the values taken from the curves by two. After ascertaining the volume in the head wall, coping, parapet, and wing-walls, the volume of the base is to be added thereto for the complete volume of the abutment. This volume of the base is taken from the two sets of curves shown in Fig. 56*p*, as explained therein.

To obtain by means of these tables the volume for any wing-abutment

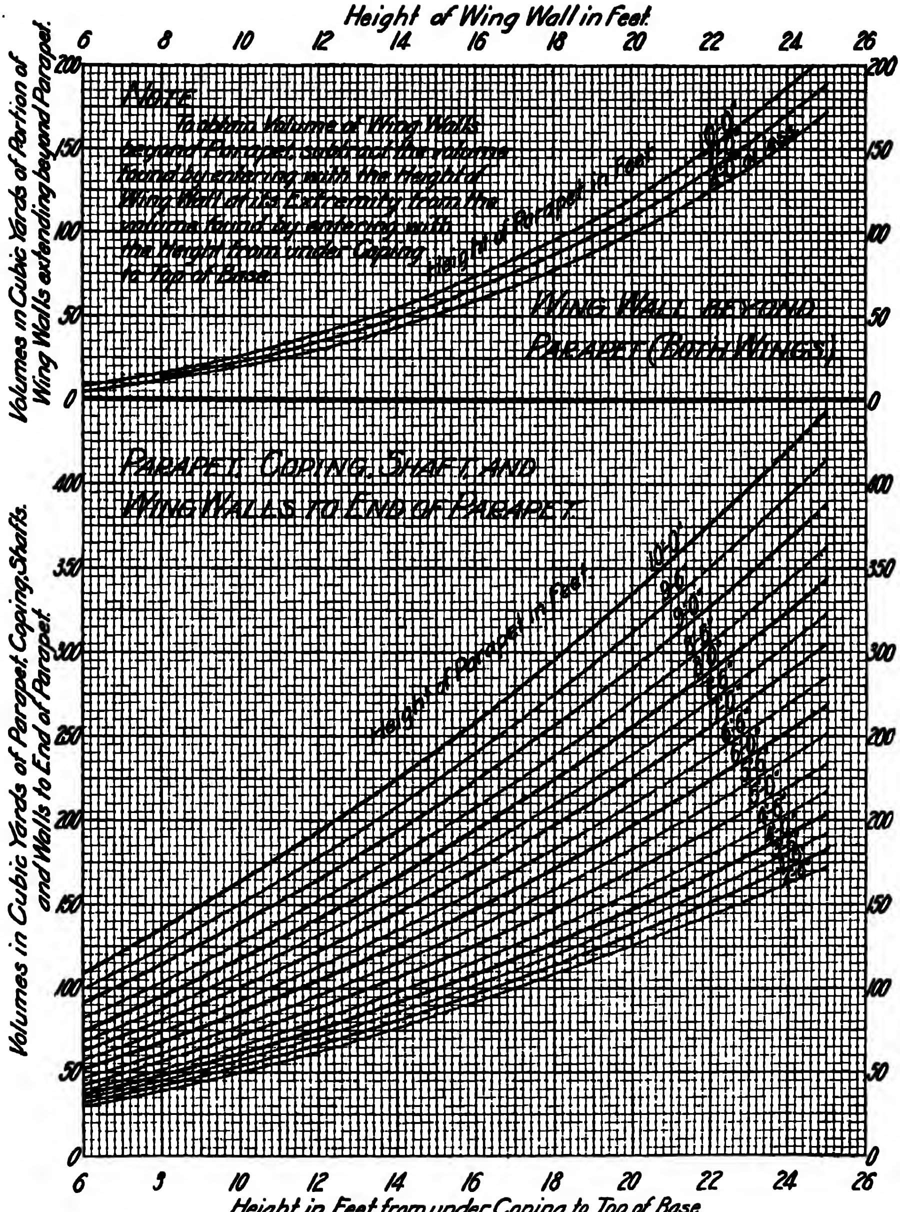


FIG. 56o. Volumes of Portions of Wing Abutments above the Base for Single-track Railway Bridges.

that is longer than that for a single-track railway bridge, it will be necessary to add the volume for the extra length of main wall. In double-track bridges the said extra length is generally thirteen or fourteen feet;

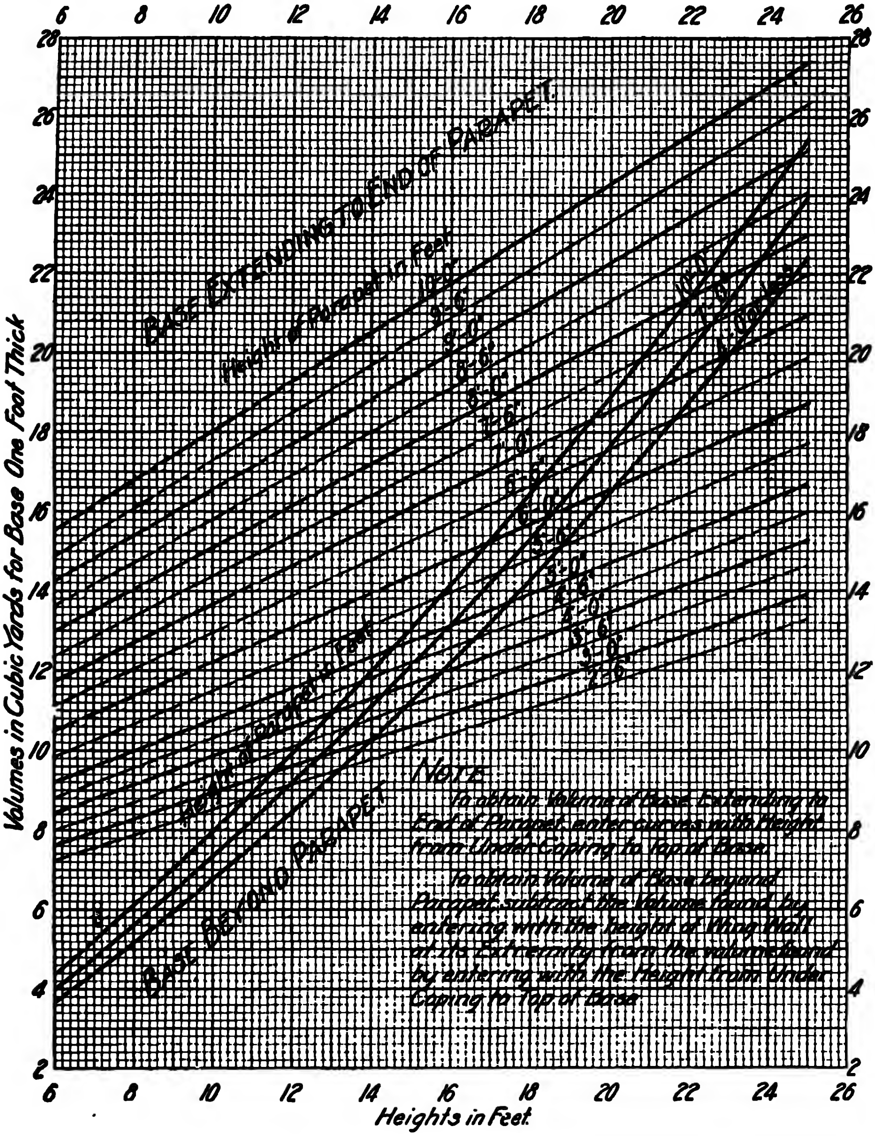


Fig. 56*p*. Volumes of Bases of Wing Abutments for Single-track Railway Bridges.

and for a highway bridge it is equal to the clear roadway between trusses, minus fifteen feet. Fig. 56*q* gives the volume in cubic yards, including parapet, coping, and shaft, for each lineal foot of wall, also the volume of base in cubic yards per lineal foot of wall for each foot of its thickness

or height. This last quantity is to be multiplied by the height of the base in feet, and the product is to be added to the volume found for the yardage of parapet, coping, and shaft per lineal foot; and the sum is

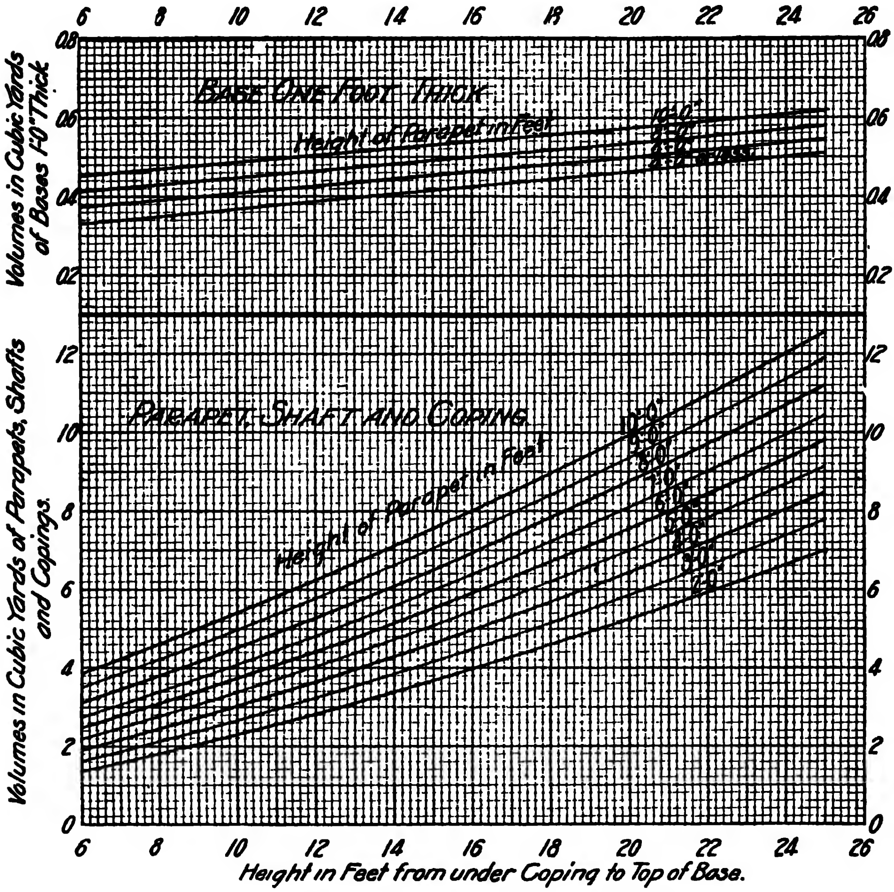


FIG. 56*q*. Volumes of Strips One Foot Wide in Middle Portions of Wing Abutments for Railway Bridges.

then to be multiplied by the total extra length of face wall. The product will be the total additional yardage for the said extra length of face wall.

Retaining Walls

Fig. 56*r* gives the quantities of concrete and metal per lineal foot of reinforced-concrete retaining walls. The curves correspond to a toe-pressure shown by the straight line above them, and if a smaller toe-pressure has to be employed the quantities given by the curves have to be increased by the ratio indicated by the right line of the small figure in the upper right-hand corner of the diagram.

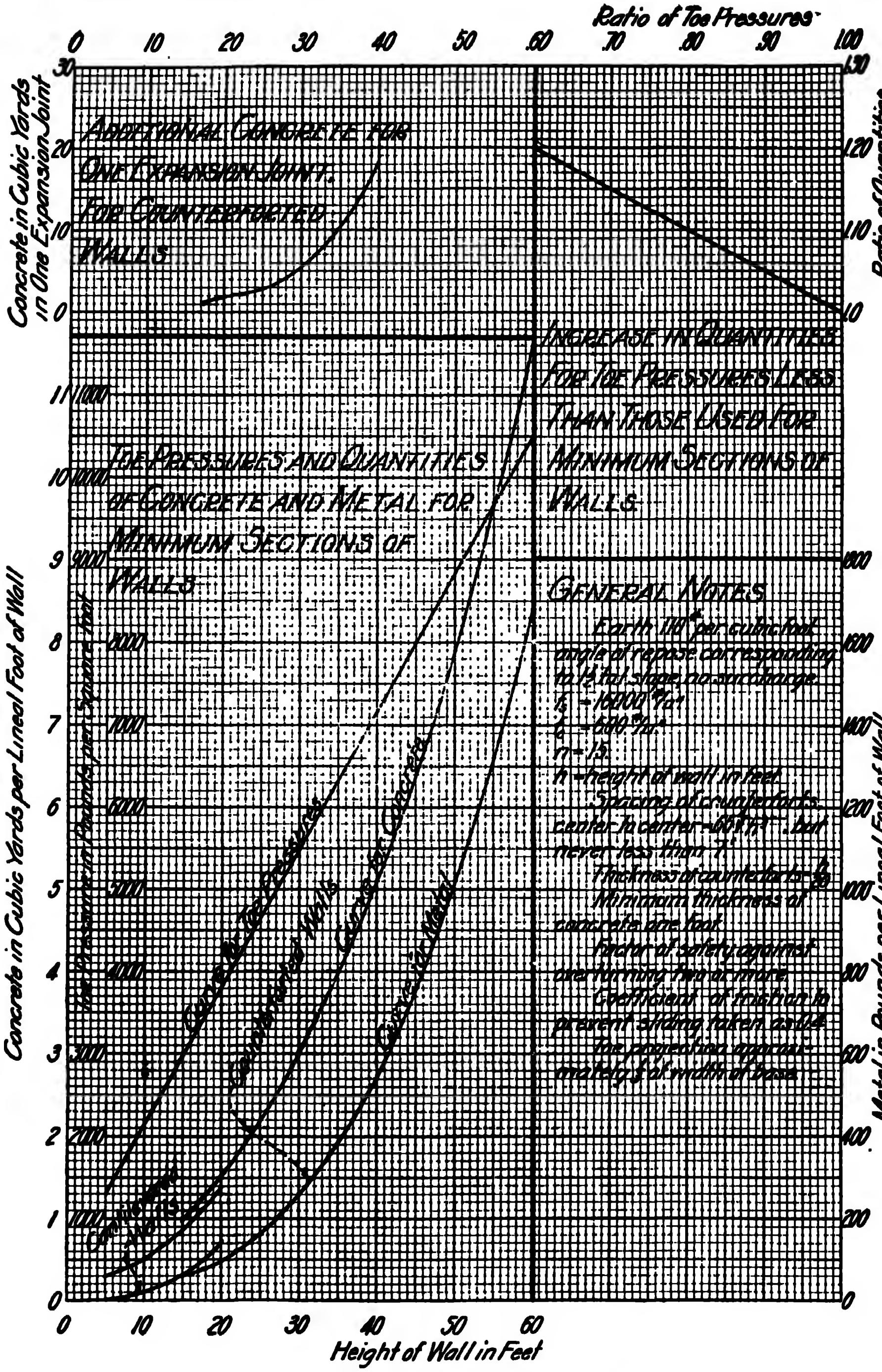


FIG. 56r. Quantities of Concrete and Metal per Lineal Foot of Reinforced-Concrete Retaining Walls.

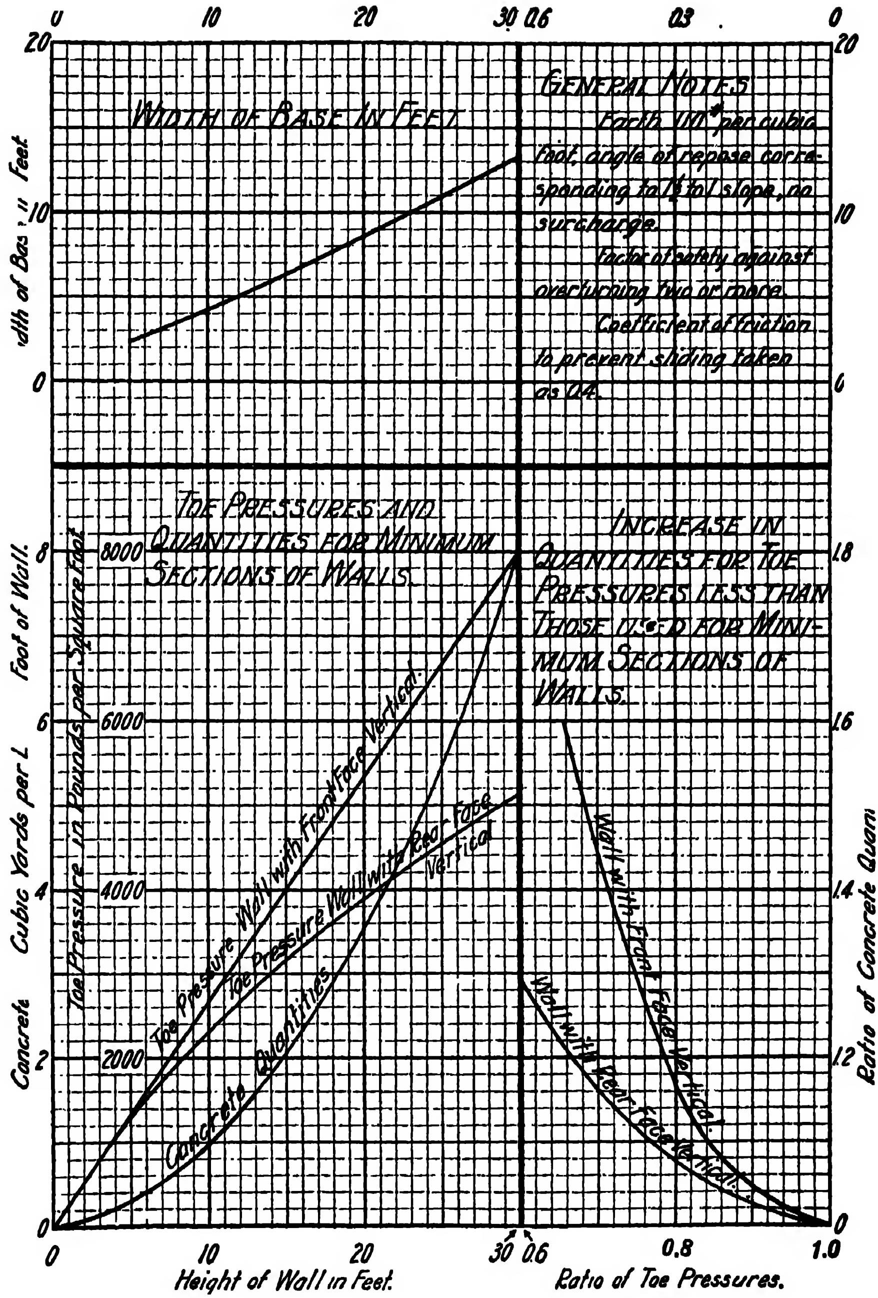


FIG. 56s. Quantities of Concrete per Lineal Foot of Plain Concrete Retaining Walls.

To show the application of the curves of this figure let us assume a case in which the height of the wall is 30 feet and the permissible toe-pressure 4,500 pounds per square foot. The diagram gives 3.0 cubic yards of concrete and 250 pounds of reinforcing metal, also a toe-pressure of 5,400. The ratio of intensities is 45 ÷ 54 = 0.83. The small diagram indicates that the quantities have to be increased about eight (8) per cent, making them 3.24 and 270 respectively.

Fig. 56*s* gives the quantities of concrete per lineal foot of plain concrete retaining walls. These curves were worked up in the same manner as those for the reinforced walls, and their application is the same.

Reinforced Concrete Bridges

In Figs. 56*t* to 56*dd*, inclusive, are given diagrams from which can be found, for all highway, electric-railway, and combined highway-and-electric-railway bridges built of reinforced concrete, the quantities of concrete and reinforcing steel required therefor. These curves are to be used for preliminary estimates only, as it is practically impossible to prepare diagrams that will furnish absolutely exact values for any given layout.

Fig. 56*t* records, for various live loads and for roadways varying in width from twenty (20) feet to sixty (60) feet, the amount of concrete and steel per lineal foot of bridge for the floor system, comprising the slab and its supporting cross-girders. A symmetrical cross-section was assumed with the floor slab supported on cross-girders which are in turn carried by two main girders. For narrow structures the girders were placed at the outside of the roadway; but for wide cross-sections the floor was cantilevered out beyond the main girders, the latter being spaced from centre to centre approximately five-eighths (⅝) of the total width of the structure. The effect of varying this spacing within reasonable limits was found to be inappreciable. The cross-girders were spaced ten (10) feet apart in all cases. The quantities in the floor systems were also figured in certain cases for spacings of cross-girders ranging from six (6) to fourteen (14) feet; however, these differences were found to affect the quantities but very slightly. For structures over thirty (30) feet wide, two sidewalks, one on each side, were adopted; but for narrower bridges the roadway was assumed to occupy the entire width. Each sidewalk was made one-sixth (⅙) of the total width. In all cases Class B uniform live load was employed in figuring the sidewalk slab. No uniform live load was used on the roadway in conjunction with concentrated live loads; and for widths under thirty (30) feet, only one truck was employed, while for greater widths two trucks were adopted. For electric-railway structures, however, Class A uniform live load was assumed on that part of the roadway outside of the twenty (20) feet occupied by the street cars. Double-track structures were assumed in all cases, because a single-track car line crossing a highway bridge is quite rare. However, if it is desirable to

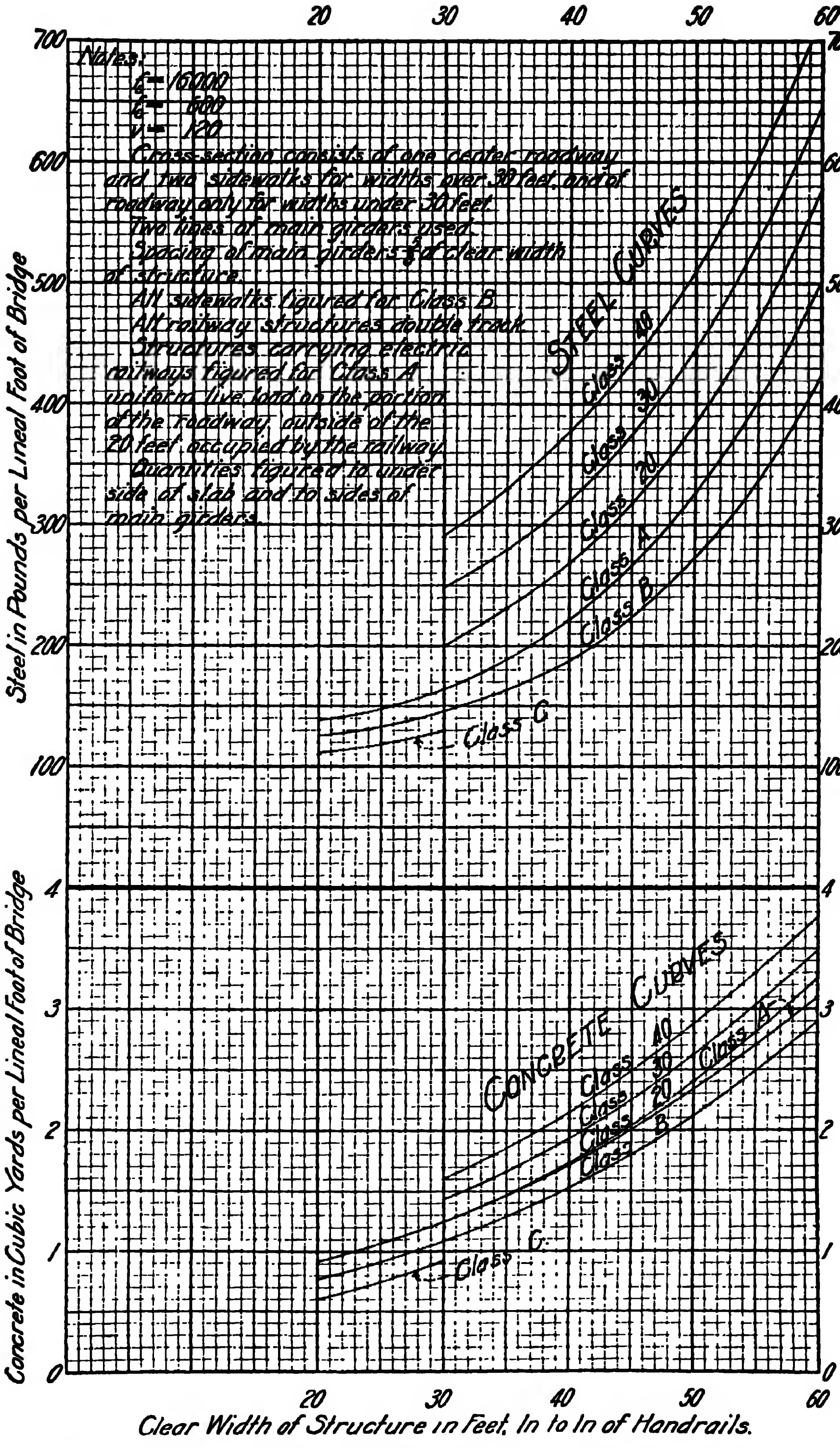


Fig. 56t. Reinforced-Concrete Bridges, Concrete and Steel in Floor System

estimate the quantities for a structure carrying a single-track Class 20 live load, the said quantities can be taken from the curves for Class A loading for the same width of structure. For other classes of electric-railway loading, the quantities for single-track structures can be taken half-way between those given by the curve for Class A and those given by the curve for a double-track structure carrying the same class of loading. On account of the fact that shear determined the sections in many instances, the steel percentage varied considerably, making it necessary to provide steel curves. The slabs were figured for the full width of the structure and the cross-girders to the sides of the main girders.

As it might be desirable in certain layouts to use several lines of longitudinal girders and omit the cross-girders, Fig. 56*u* has been inserted.

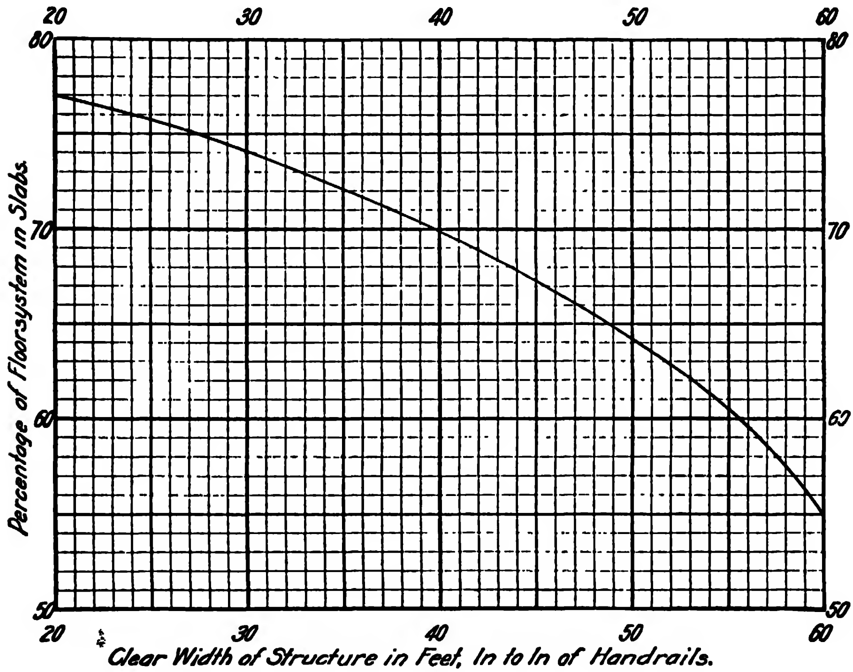


FIG. 56*u*. Reinforced-Concrete Bridges, Percentage of Floor System in Slabs.

This curve gives the percentage of the floor system in the slabs only. It will be found that for an economical arrangement, the slab quantities in the layout with longitudinal girders only will be about the same as in the design with cross-girders.

In Fig. 56*v* are recorded for various total superimposed loads per lineal foot of girder, and for span lengths varying from twenty (20) to sixty (60) feet, the quantities of materials in the main girders of reinforced-concrete bridges. These quantities were computed for single-girder spans freely supported, two-girder spans continuous over three supports, and three or more girder spans continuous over four or more supports, all

spans being assumed of equal length. The dead load was taken equal to twice the live load, which is a fair average of the conditions for reinforced-concrete bridges; but a considerable change in this ratio will affect the quantities very little.

The section at the support is determined by moment or shear; and for any one layout the depths at all supports are made equal. The

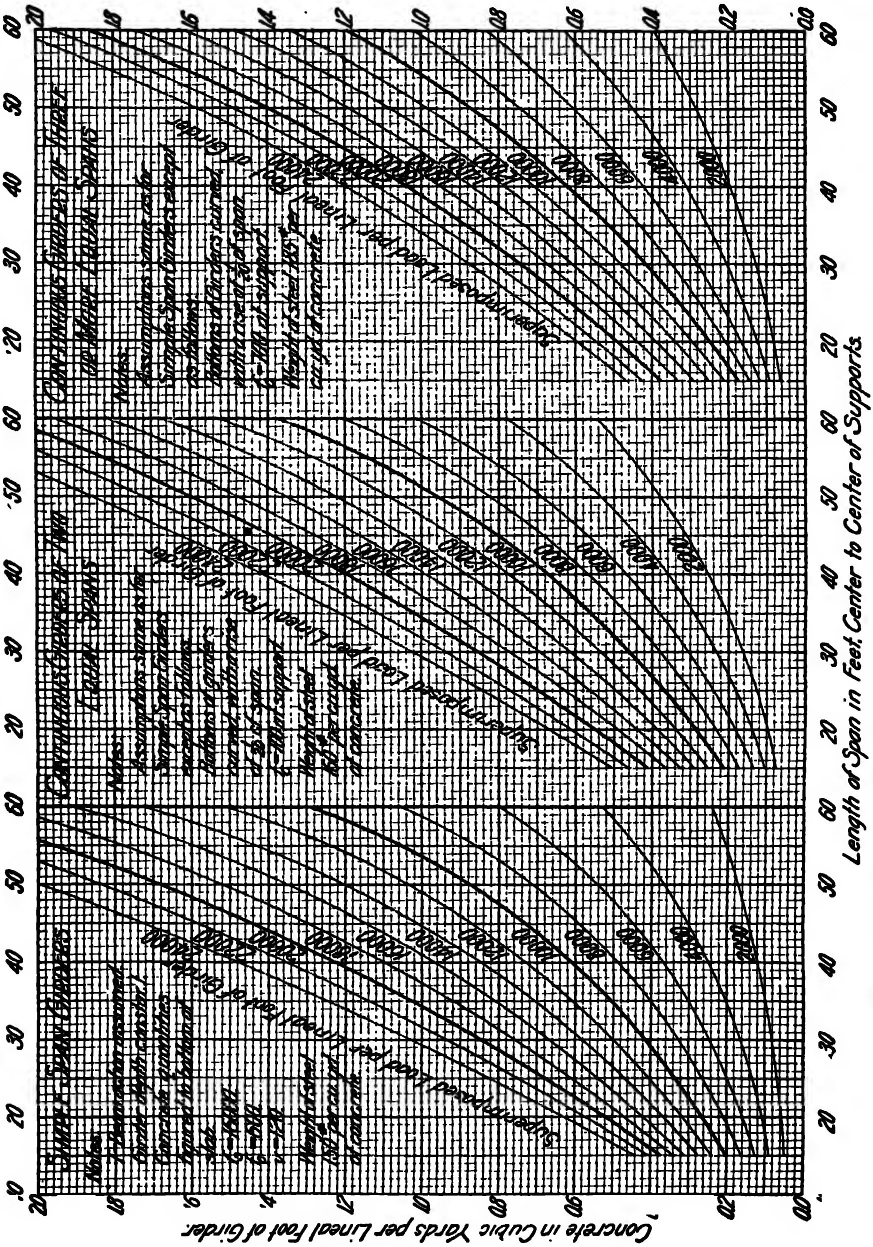


Fig. 56v. Reinforced-Concrete Girder Bridges, Concrete and Steel in Main Girders.

depth at the centre of span is assumed to be nineteen-twentieths of that at the support for continuous spans, in order to provide a slight upward curve in the bottom of the girder; while for simple girder spans the depth is kept constant throughout. Reinforcement is placed in the girder below

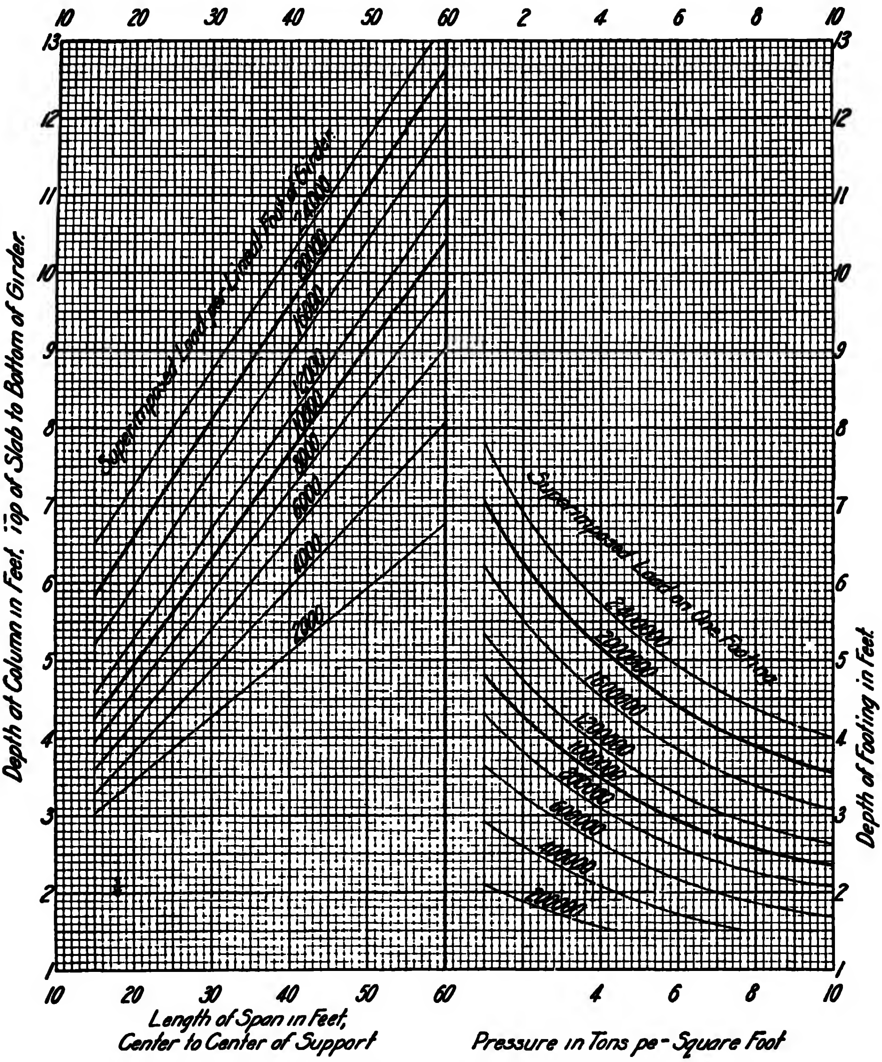


FIG. 56w. Reinforced-Concrete Girder Bridges, Depths of Girders and Footings.

the slab, so that at the support the beam is figured for the rectangular section beneath the said slab. T-beam action is assumed at the centre of span. The average thickness of slab was taken as eight (8) inches. The concrete quantities for the girders were computed from under side of slab to bottom of girders.

It should be kept clearly in mind when using Fig. 56v that the diagram

is drawn for the *superimposed* load (exclusive of that of the girder itself) and not for the *total* load per lineal foot of girder, as is the case in the curves for steel girders given in Chapter LV. The quantities, of course, were worked out for total loads. As it is somewhat difficult to approximate the sections of concrete girders with sufficient accuracy, it saves considerable time to enter the curves for the *superimposed* load.

These curves are not applicable for layouts of continuous girders with irregular span lengths in which the variation is considerable. Where the end spans are longer than the intermediate ones the actual quantities will be greater than those given by the curves, if the diagram be entered with the average span length; whereas, when the intermediate spans are the longer, the actual quantities will be smaller. For layouts in which the differences in span lengths are small, the curves will give sufficiently accurate quantities for the given layout if they are entered with the average span length.

Fig. 56*w* records the depth of girder and depth of column footing for various loads per lineal foot of girder and total loads on footing. This diagram will be found convenient in determining the height of column which is necessary when employing Fig. 56*x*.

In Fig. 56*x* are given, for various total superimposed loads and for heights of columns varying from ten (10) feet to one hundred (100) feet, the total quantity of concrete in one column; and Fig. 56*y* records the corresponding weight of steel per cubic yard of concrete. The section of the column was assumed square in all cases, and no transverse bracing was used. The section of the column just under the girder was determined for the full superimposed load, the gross section of the concrete being figured for f equal to $640 - 20 \frac{l}{b}$, but not greater than 400 pounds per square inch. This corresponds to an actual intensity on the concrete of about 350 pounds on account of the reinforcement. The value of $\frac{l}{b}$ was not allowed to exceed 20. This section was reinforced with one per cent of steel, and the same steel area was used throughout the entire column. The columns have a batter of one-eighth of an inch per vertical foot on all four faces. The concrete quantities were figured from top of column (under side of longitudinal girder) to top of footing; but the steel quantities included all bars extending from the column into the girders and footings. This is the reason for the large amount of steel per cubic yard of concrete.

In Fig. 56*z* are recorded for various total superimposed loads on footings, and for bearing pressures ranging from one (1) ton to fourteen (14) tons per square foot, the volumes of concrete required per column-footing in reinforced-concrete viaducts. Each of these footings has a constant depth throughout, it being made sufficient to provide for shear by means

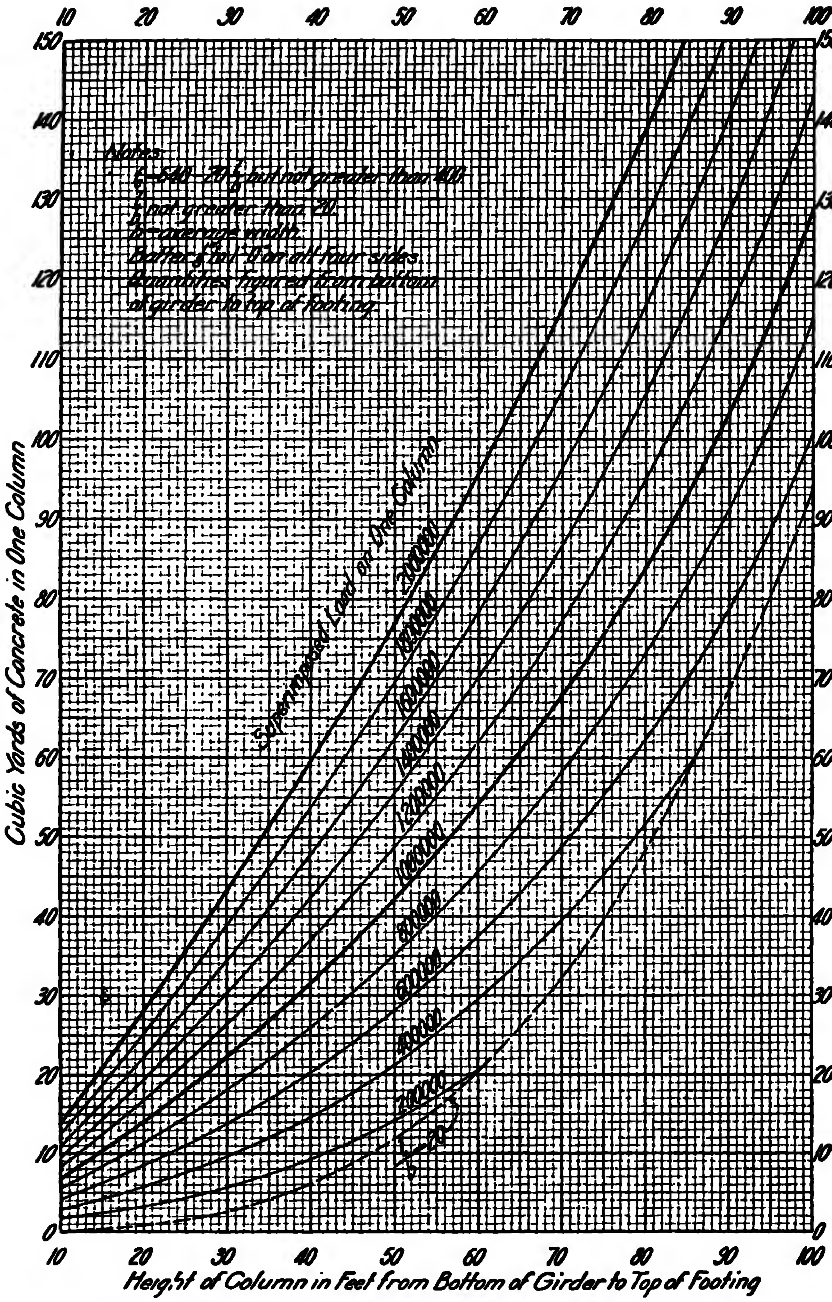


Fig. 56x. Reinforced-Concrete Girder Bridges, Concrete in Columns.

of the concrete alone. It will be noted that there are two sets of curves—one for reinforced, the other for plain footings. The latter were figured for a fibre stress from bending not to exceed 70 pounds per square inch (on 1:2:4 concrete), although in most cases the shear determined the section. The footings are assumed to be supported on the natural foundation. In case piles are employed, the concrete necessary to encase their heads must be added to the quantities given in the diagram for reinforced footings.

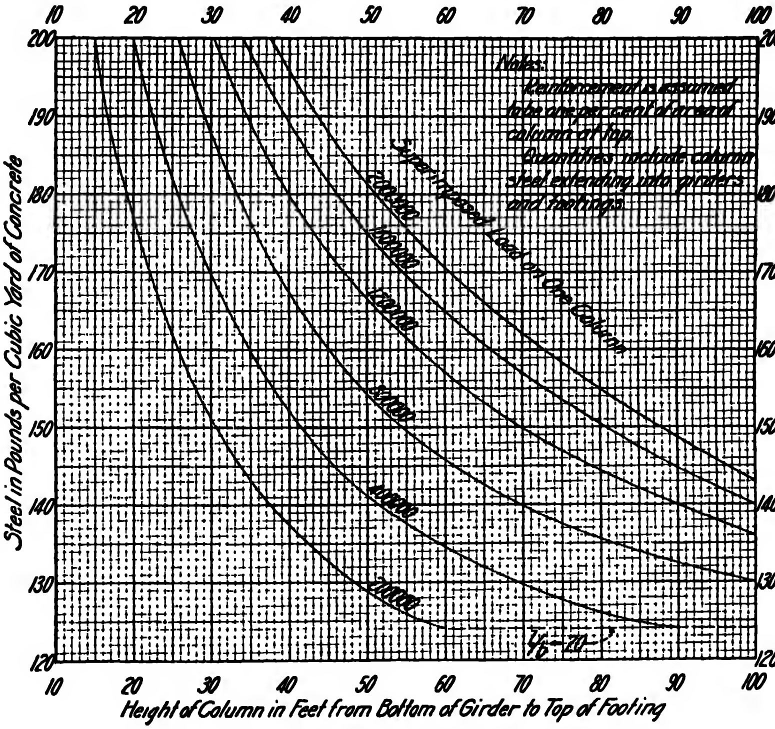


FIG. 56y. Reinforced-Concrete Bridges, Steel in Columns.

As indicated in Chapter LIII, the economic span length in a reinforced-concrete trestle for any given layout can be determined by the equation,

$$l = h\left(0.3 + \frac{2,000}{w + 1,000}\right); \qquad \text{[Eq. 1]}$$

in which l = economic span length from centre to centre of supports,

w = superimposed load per lineal foot of girder,

and h = height of structure.

The quantity h represents in any given case the height which is fixed, such as the height from grade to top of footing, height from grade to bottom of footing, height from underside of girder to top of footing, or height from underside of girder to bottom of footing, as the case may be. There is always a considerable range of length for which the quantities

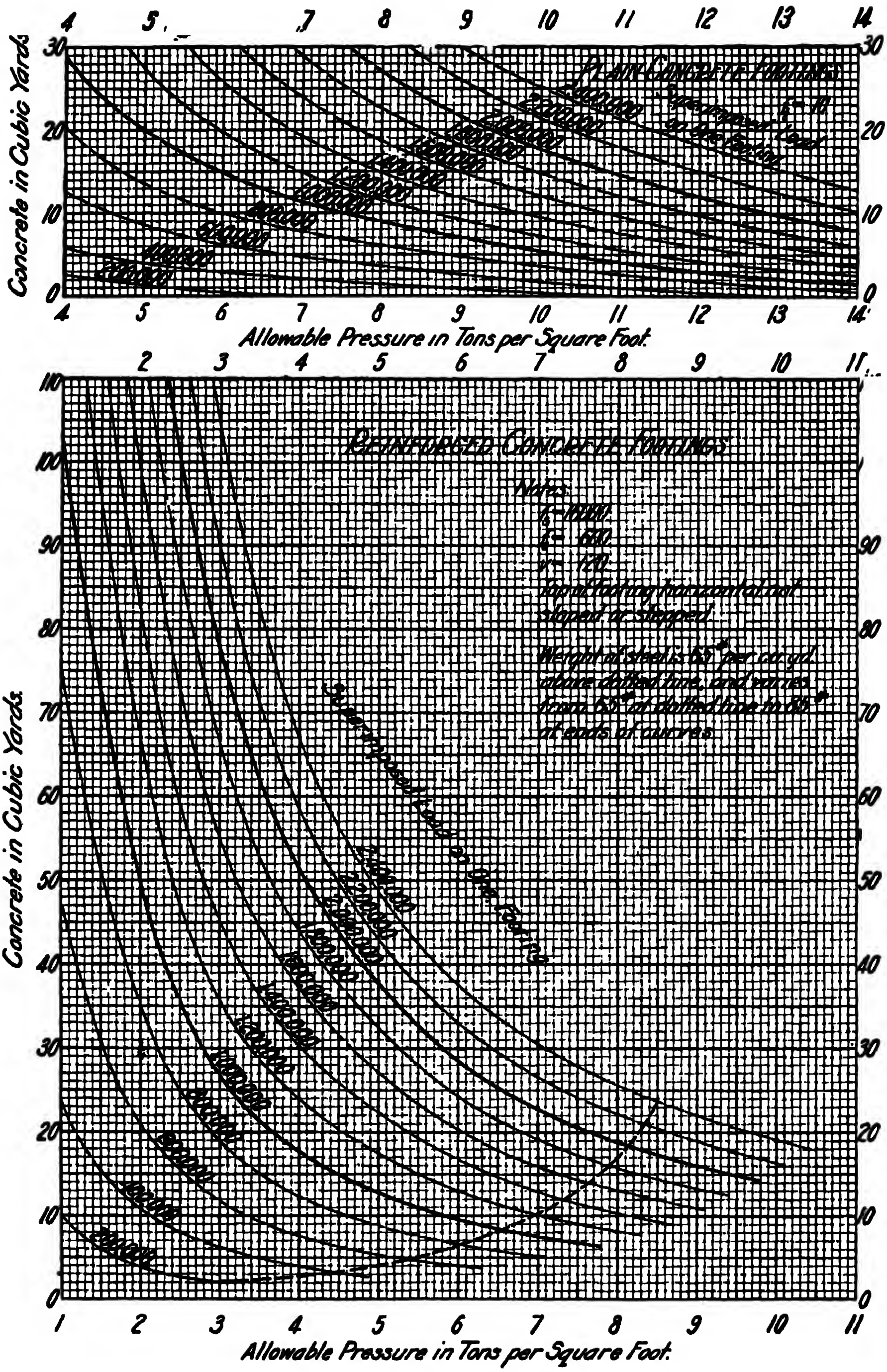


FIG. 56z. Reinforced-Concrete Girder Bridges, Concrete and Steel Footings.

remain nearly constant. The formula gives values a trifle greater than those for which the quantities are a minimum, since the use of heavier sections will reduce slightly the unit costs of the concrete.

In Fig. 56*aa* are diagrammed the quantities of concrete per lineal foot of structure in the spandrel girders and columns of open-spandrel arches. The steel is given in pounds per cubic yard of concrete. These quantities

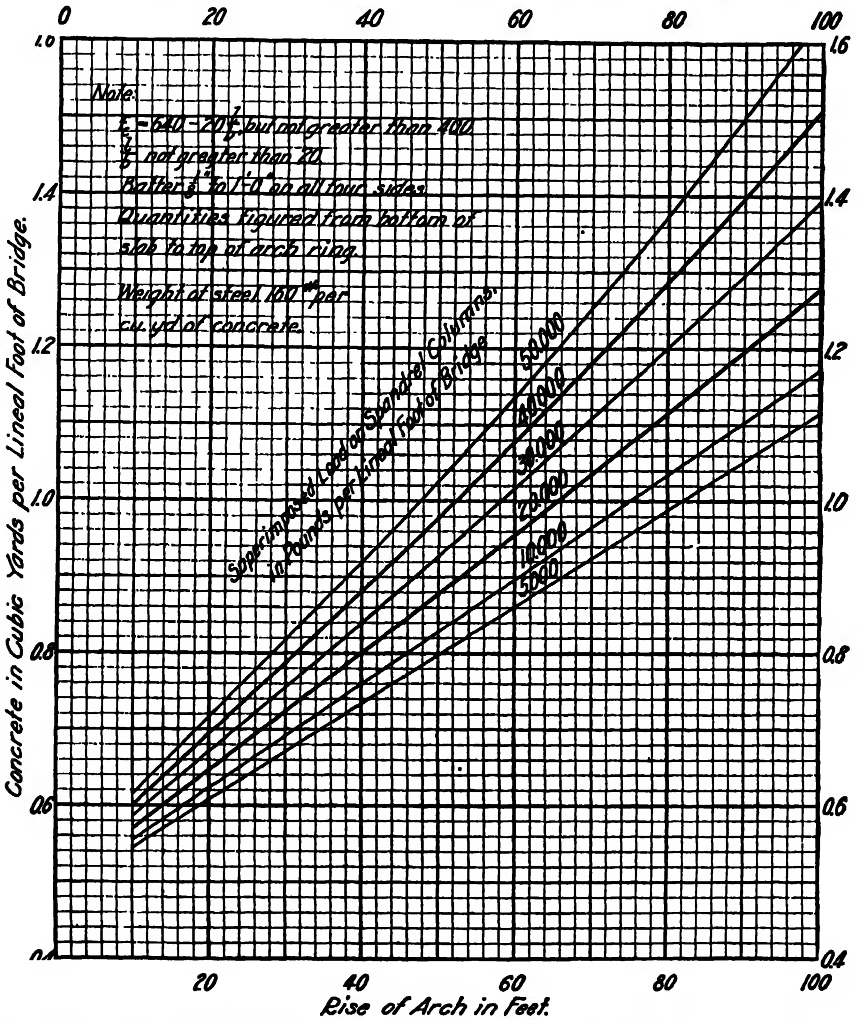


FIG. 56*aa*. Reinforced-Concrete Arch Bridges, Concrete and Steel in Spandrel Girders and Columns.

are more or less arbitrary, although dependent to a large degree on the rise of the arch. As a rule, æsthetic treatment determines the proportions of the spandrel girders and columns. However, the quantities are not a large proportion of the total quantities in the structure; and, therefore, a considerable variation therein will not be appreciable.

For barrel arches the cost of the structure above the rib will not be materially different from that of the ribbed spans, and consequently the quantities for the latter will be sufficiently accurate for barrel arches.

In Fig. 56*bb* are recorded, for the cantilever and counterforted types and for heights of wall up to fifty (50) feet, the volumes of concrete and weights of metal per lineal foot of structure in the spandrel walls of reinforced-concrete, spandrel-filled arch bridges. In nearly all cases it will be sufficiently accurate to enter these curves with the average height of the wall. These quantities are given for walls without surcharges; and where it is necessary to consider surcharge, the quantities can be taken with sufficient accuracy for a height equal to the actual height without surcharge plus seven-tenths (0.7) of the surcharge height. Quantities for side walls with transverse ties are not given, as it is practically impossible to do so on account of variations in the layouts; but the quantities recorded in Fig. 56*bb* can be used, although they are a trifle excessive for this type of construction.

In Fig. 56*cc* are recorded, for various superimposed total loads per lineal foot at crown, for span lengths varying from fifty (50) feet to two hundred (200) feet, and for ratios of rise to span length ranging from 0.1 to 0.5, the volumes of concrete in one rib per lineal foot of span required in the arch ribs of open-spandrel arch spans. The weights of steel are given in pounds per cubic yard of concrete. The curves were worked up on the assumption that the live load was four-tenths (0.4) of the total superimposed load per foot at the crown (exclusive of the weight of the rib itself). But to take care of variations in the ratio of live load to total superimposed load, the curves were platted for an equivalent superimposed load equal to $W\left(0.6 + \frac{L}{W}\right)$. It will be noted that this expression is equal to the actual superimposed load when $\frac{L}{W}$ equals 0.4. The width of each rib was kept constant throughout, and was taken equal to or greater than the thickness at the springing. The amount of reinforcement used in each face varied from one per cent for a rise of one-tenth of the span to one-half of one per cent for a rise of one-half of the span.

The separate ribs of ribbed-arch structures must be braced together by cross-struts, except occasionally in the case of arches carrying heavy loads for which the ratio of rise to span-length is 0.2 or less. To determine whether bracing is required for such ribs, the load on the rib should be divided by the economic carrying capacity of the rib—determined from Fig. 56*dd*—thus giving the width of the rib; and braces should be employed whenever the ratio of unsupported length to width of rib is greater than twelve (12). In most cases this unsupported length is the distance from the crown to the springing, as the cross-girders usually brace the ribs effectively at the crown. The volume of the braces is more or less

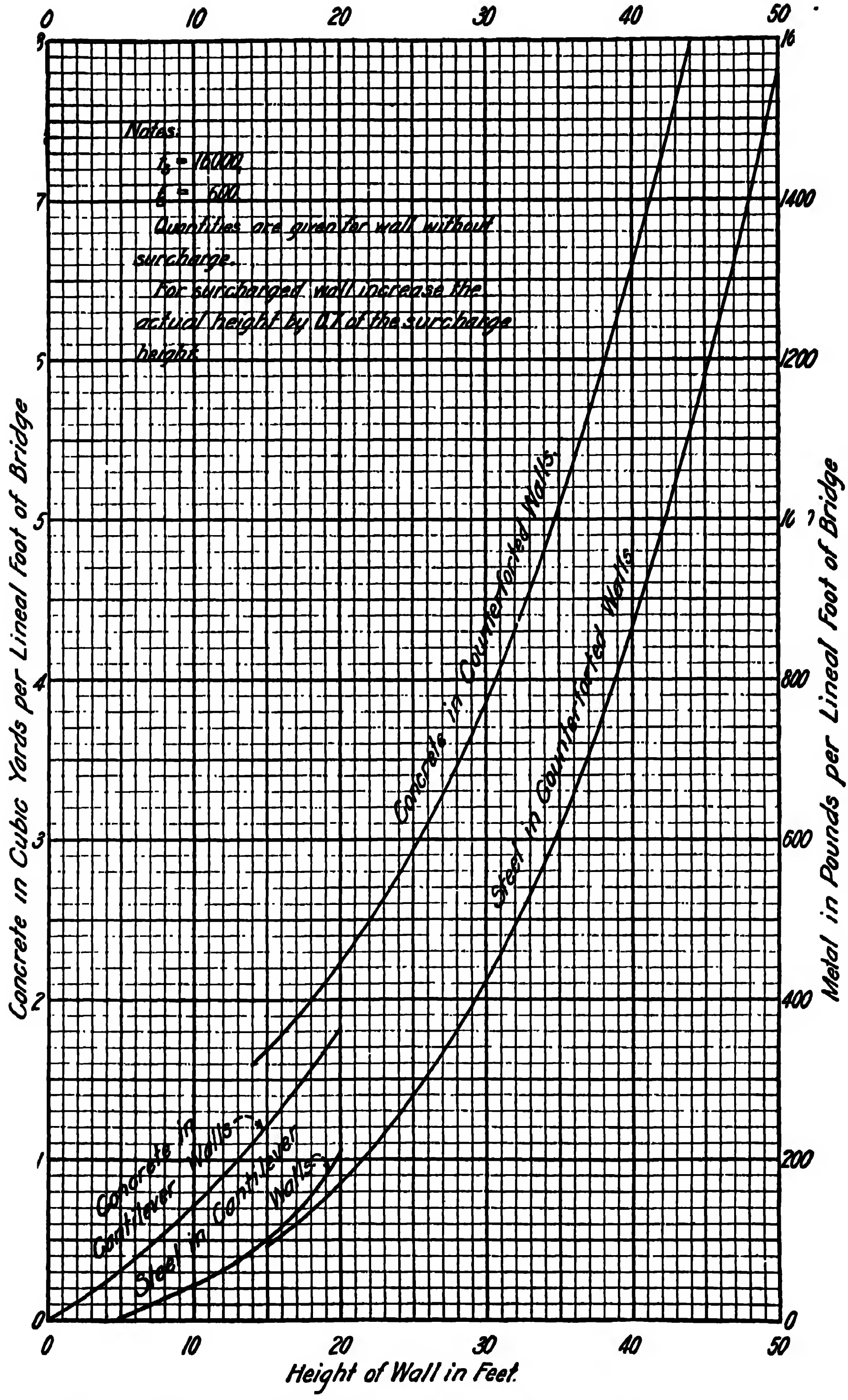


FIG. 56*bb*. Reinforced-concrete Arch Bridges, Concrete and Steel in Spandrel Walls.

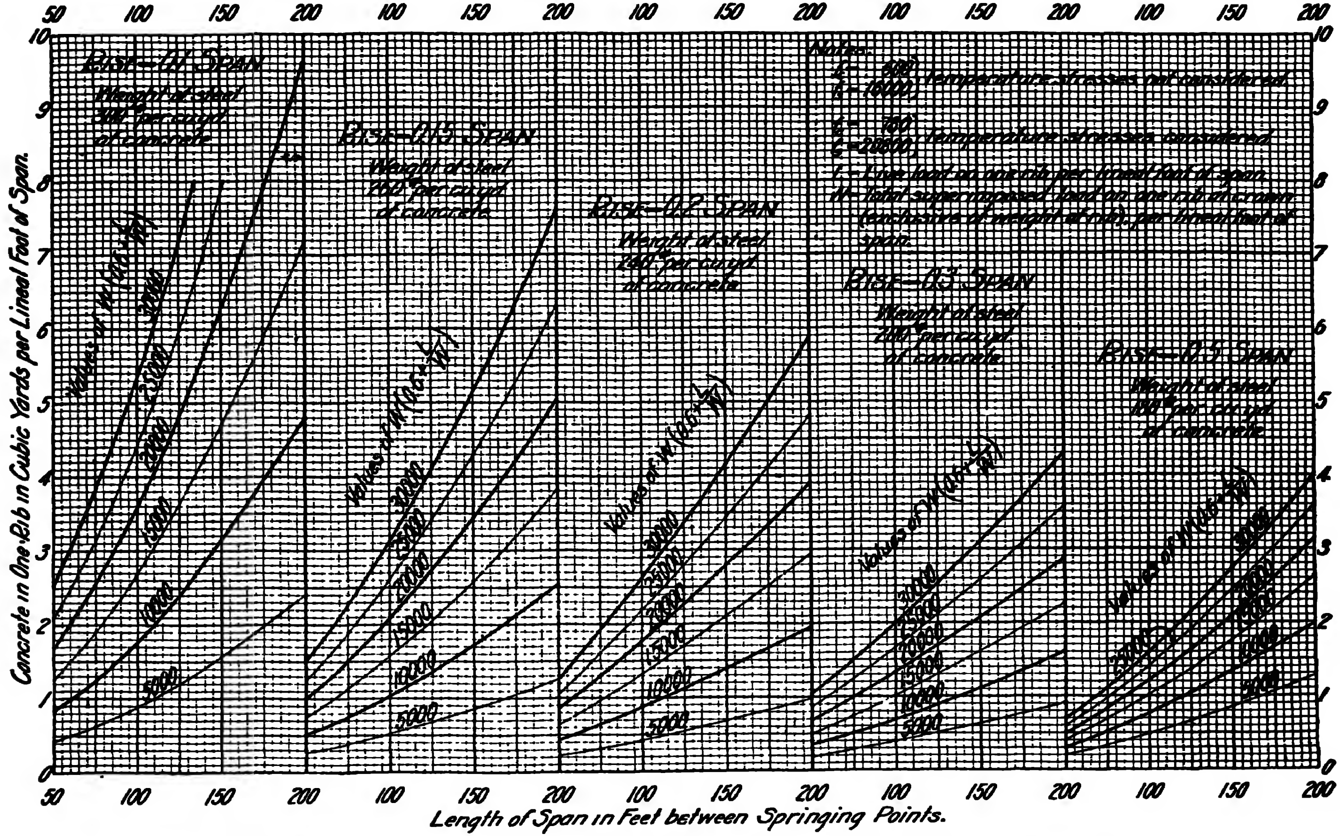


FIG. 56cc. Reinforced-Concrete Arch Bridges, Concrete and Steel in Arch Ribs.

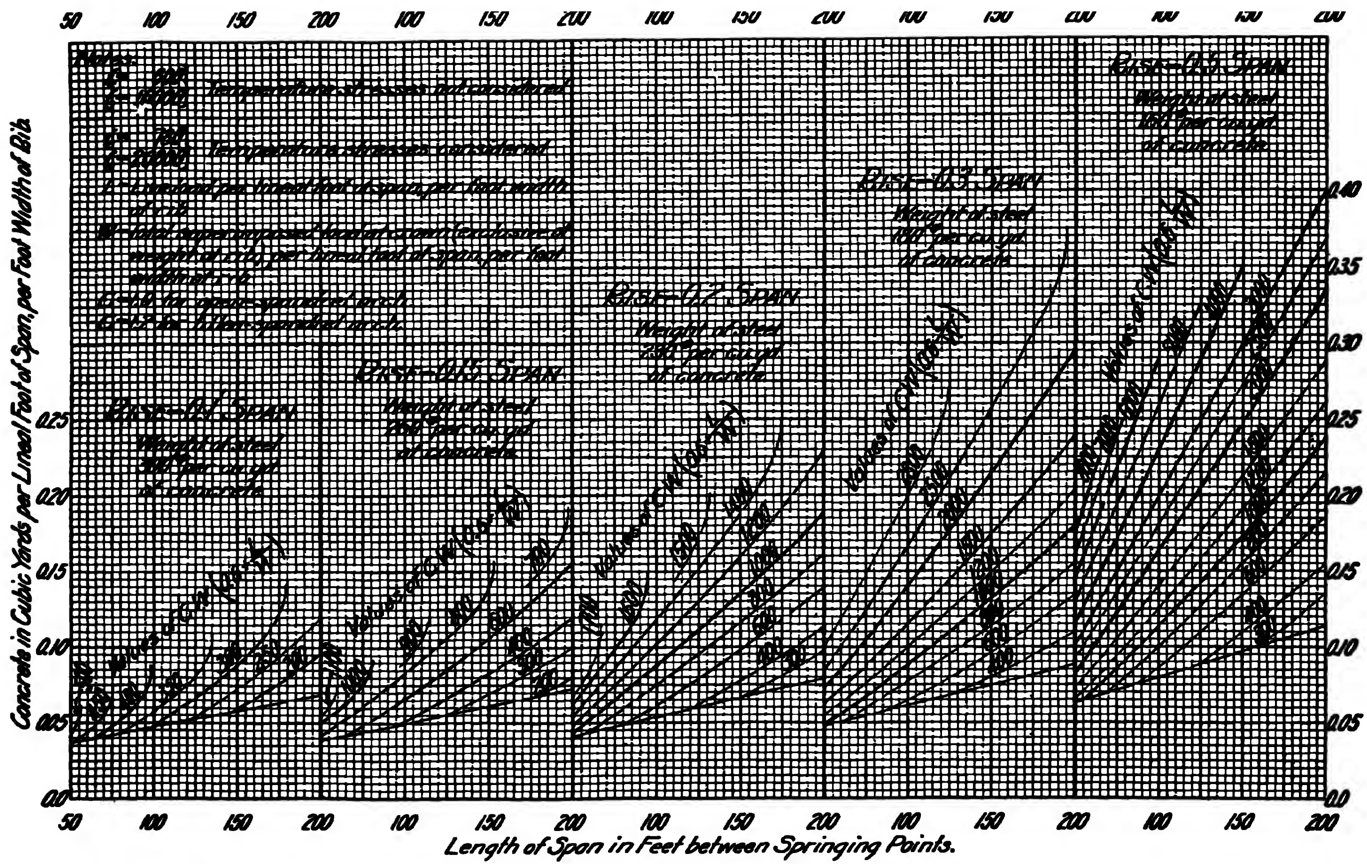


Fig. 56*dd*. Reinforced-Concrete Arch Bridges, Concrete and Steel in Arch Barrels One Foot Wide.

arbitrary, depending on the judgment of the designer; but it will usually be from ten to twenty-five per cent of the volume of the ribs themselves, the smaller value holding for closely spaced flat ribs carrying heavy loading, and the larger one for widely spaced ribs of high rise carrying light loading.

Fig. 56*dd* gives the quantities in ribs one foot wide, for either open-spandrel or solid-spandrel arches. The curves were worked up for open-spandrel arches in which the live load was four-tenths (0.4) of the total superimposed load per foot at the crown (exclusive of the weight of the rib itself); and the quantity $CW\left(0.6 + \frac{L}{W}\right)$ takes care approximately of the effect of variations in the live load to total superimposed load ratio and of the addition of the filling in the spandrel-filled structure. It will be noted that this expression equals the total superimposed load per foot for an open-spandrel arch in which $\frac{L}{W}$ equals 0.4. The curves are evidently applicable to ribs of any width; and where the width can be varied, they can be used to determine the most economic rib. In the case of open-spandrel structures, it is thus possible to determine whether the ribbed type or the solid-barrel type is the cheaper, remembering, of course, that the ribbed type will require cross-braces. The curves of Figs. 56*cc* and 56*dd* are entirely consistent, those of the former having been derived directly from those of the latter. A little extra steel was added in the sides of the ribs of high rise.

It will be found that a considerable change can be made in the concrete quantities of Figs. 56*cc* and 56*dd* by varying the percentages of steel; but the total cost of any rib will not be greatly affected thereby. Except for the ribs in which the rise is one-half of the span, the curves show the maximum carrying capacities of the ribs for the percentages of reinforcement adopted; but these capacities can be increased by using more steel, with but little loss of economy. However, this should rarely be necessary. The minimum curves were determined by judgment. For a load below the minimum plotted carrying-capacity of a rib, the amount of steel per cubic yard of concrete can, of course, be reduced somewhat below the value given on the diagram.

The two following examples will illustrate the use of Figs. 56*t* to 56*dd*, inclusive.

A. What is the economic span length for a reinforced-concrete trestle for a long structure to carry a double-track electric railway of Class 25 live load at the middle of a creosoted-block-paved roadway, 44 feet wide, figured to support Class A live loading, also two 8-foot sidewalks to carry Class B live loading, the distance from ground to grade being 40 feet, the permissible pressure on the foundation soil being 2.5 tons per square foot, and the depths of the foundations below ground level being 10 feet?

What are the quantities per lineal foot of span for the various portions of the structure?

Floor System

Concrete per lin. ft. of structure (Fig. 56*t*) .... = 3.35 cu. yds.
Steel per lin. ft. of structure (Fig. 56*t*) .... = 610 lbs.

Main Girders

Dead Load (per lineal foot of structure):

Floor system	= 3.35 × 4,000	= 13,400 lbs.	
Pavement	= 44 × 25	= 1,100 "	
Track base	= 20 × 75	= 1,500 "	
Rails, etc.	=	100 "	
Handrails	= 2 × 400	= 800 "	
Total dead load			= 16,900 lbs.

Assume a span length of 30′ (loaded length of 60′).

Live Load (per lineal foot of structure):

Class 25 (Fig. 6*h*)	= 2 × 2,290	= 4,580 lbs.	
Impact (Fig. 7*d*)	= 41%	= 1,880 "	
Class A (Fig. 6*o*)	= 24 × 111	= 2,670 "	
Impact (Fig. 7*e*)	= 31%	= 840 "	
Class B (Fig. 6*o*)	= 16 × 92	= 1,470 "	
Impact (Fig. 7*e*)	= 31%	= 460 "	
Total live load			= 11,900 lbs.

Total load per lin. ft. of structure .... = 28,800 lbs.

Total load per lin. ft. of girder (two girders per span) .... = 14,400 lbs.

By Eq. 1, we have for the economic span,

$$l = 50\left(0.3 + \frac{2{,}000}{14{,}400 + 1{,}000}\right) = 21.5.$$

Hence we shall assume a span length of 20′.

Live Load (per lineal foot of structure):

Loaded length		= 40′	
Class 25 (Fig. 6*h*)	= 2 × 2,650	= 5,300 lbs.	
Impact (Fig. 7*d*)	= 47%	= 2,500 "	
Class A (Fig. 6*o*)	= 24 × 114	= 2,740 "	
Impact (Fig. 7*e*)	= 36%	= 990 "	
Class B (Fig. 6*o*)	= 16 × 95	= 1,520 "	
Impact (Fig. 7*e*)	= 36%	= 550 "	
Total live load			= 13,600 lbs.

Total load per lin. ft. of structure .... = 30,500 lbs.

Total load per lin. ft. of girder		= 15,300 lbs.
Concrete per lin. ft. of girder (Fig. 56*v*)		= 0.37 cu. yds.
Steel per lin. ft. of girder (Fig. 56*v*)	= 0.37 × 185	= 70 lbs.
Concrete per lin. ft. of structure	= 2 × 0.37	= 0.74 cu. yds.
Steel per lin. ft. of structure	= 2 × 70	= 140 lbs.
Weight of one girder per lin. ft.	= 0.37 × 4,000	= 1,480 lbs.

Columns

Load on column from girder................	= 21.5 (15,300 + 1,500)	= 362,000 lbs.
Depth of girder (Fig. 56*w*).................	= 5.8′	
Depth of footing (Fig. 56*w*)................	= 2.7′	
Distance grade to top girder................	= 1.0′	
Total................................	= 9.5′	
Height of column........................	= 50′ − 9.5′ = 40.5′	
Concrete in one column (Fig. 56*x*)...............................		= 14 cu. yds.
Steel in one column (Fig. 56*y*)..............	= 14 × 150	= 2,100 lbs.
Concrete in columns per lin. ft. of structure..	= 2 × 14 ÷ 20	= 1.4 cu. yds.
Steel in columns per lin. ft. of structure......	= 2 × 2,100 ÷ 20	= 210 lbs.
Weight of one column.....................	= 14 × 4,000	= 56,000 lbs.

Footings

Load on footing..........................	= 362,000 + 56,000	= 418,000 lbs.
Concrete in one footing (Fig. 56*z*)...............................		= 9 cu. yds.
Steel in one footing (Fig. 56*z*)..............	= 9 × 65	= 585 lbs.
Concrete in one footing per lin. ft. of structure.	= 2 × 9 ÷ 20	= 0.9 cu. yds.
Steel in one footing per lin. ft. of structure...	= 2 × 585 ÷ 20	= 60 lbs.

SUMMARY OF QUANTITIES

Part of Structure	Concrete (Cu. Yds.)	Steel (Pounds)
Floor system....................................	3.35	610
Girders..	0.74	140
Columns...	1.4	210
Footings..............	0.9	60
Total...	6.39	1,020

B. For the same type of floor and loading as in the preceding reinforced-concrete trestle example, what will be the various quantities of concrete in the different parts (excluding abutments) of an arch bridge having a single, 150-foot-clear span (or 160′ between springings), of which the rise is 32 feet, the arch being open-spandrel?

Floor System

(See preceding problem)

Concrete per lin. ft. of structure.................................		= 3.35 cu. yds.
Steel per lin. ft. of structure....................................		= 610 lbs.

Spandrel Girders and Columns

Assume load on spandrel columns per lin. ft. of structure same as for main girders in the preceding problem........................		= 30,500 lbs.
Concrete per lin. ft. of structure (Fig. 56*aa*)......................		= 0.77 cu. yds.
Steel per lin. ft. of structure (Fig. 56*aa*)...........	= 0.77 × 130	= 100 lbs.

Arch Ribs

Superimposed Load at Crown:

Dead Load **(as for girder spans)**			= 16,900 lbs.
Spandrel girders		= 0.77 × 4,000	= 3,100 "
Live Load **(for 80′ span):**			
Class 25 (Fig. 6*h*)	= 2 × 2,040	= 4,080 lbs.	
Impact (Fig. 7*d*)	= 36%	= 1,470 "	
Class A (Fig. 6*o*)	= 24 × 108	= 2,590 "	
Impact (Fig. 7*e*)	= 28%	= 730 "	
Class B (Fig. 6*o*)	= 16 × 90	= 1,440 "	
Impact (Fig. 7*e*)	= 28%	= 400 "	
Total live load			= 10,710 lbs.
Total load per lin. ft of structure			= 30,710 lbs.
Total load per lin. ft. of rib (two ribs per span)			= 15,400 lbs.
Rise			= 0.2 span
Concrete per lin. ft. of structure (Fig. 56*cc*)		= 2 × 2.4	= 4.8 cu. yds.
Steel per lin. ft. of structure (Fig. 56*cc*)		= 4.8 × 240	= 1,150 lbs.

Braces

Economic carrying capacity of rib (Fig. 56*dd*)	= 1,300 lbs. per ft. width
Width of rib	= 15,400 ÷ 1,300 = 12′
Unsupported length	= 80′

Evidently no braces are needed.

SUMMARY OF QUANTITIES

Part of Structure	Concrete (Cu. Yds.)	Steel (Pounds)
Floor	3.35	610
Spandrel girders and columns	0.77	100
Arch ribs	4.80	1,150
Total	8.92	1,860

ARCH PIERS AND ABUTMENTS

Owing to the great number of the variables which affect the quantities of materials in the piers and abutments of reinforced-concrete arch bridges, it is entirely impracticable either to record the said quantities by diagram or to give any fairly approximate simple rule for their quick computation. Concerning this matter the author speaks advisedly; for he personally wasted a whole week of ten or twelve working hours per day in trying to establish a formula therefor, involving the following variables: length of structure, width of deck, average live load (including impact) per square foot of floor, average ratio of rise to span, average height of piers and abutments, average intensity of pressure on foundations, average ratio for all piers of the inequalities (greater than unity) of the two

adjacent clear span-lengths, average length of span for entire bridge, number of spans in structure, and average for all piers of the vertical distances from the lowest part of base to the point of application of the resultant of the two thrusts. These variables were properly taken care of in the tentative equations; and approximately correct rules for their methods of variation were established, as hereinafter indicated. The author had at hand properly digested and tabulated data for eight large arch structures; but, unfortunately, there were other variables than the preceding ones involved in their designing which prevented any satisfactory systemization—for instance, one bridge was built as light as the engineers' consciences would allow in order to meet a fixed appropriation, while another was made very massive for æsthetic effect to suit the requirements of a client; two bridges had ice-breaks, while the others had none; some of the decks were cantilevered out beyond the piers, while the others were not; some arches were ribbed, while others were solid-barrelled; some structures with unequal adjacent spans had their points of springing adjusted so as to keep down the overturning moments on the piers, while in others the springing points on each pier were at the same elevation; one bridge alone had a double-deck; and one structure had two abutment piers, while none of the others had any. As a climax to all these variations were the personal equations of the various computers—and these in reinforced-concrete work are by no means inconsiderable, varying often by many per cent—but (worse yet!) the fact that the mental condition of the individual computer changes from time to time has an influence on concrete quantities that is far from being negligible. Much to his regret, the author had to abandon his intention of preparing two or three general formulæ for concrete quantities in the piers and abutments of the various kinds of reinforced-concrete arch bridges. Such a set of equations would have rounded out in fine shape the tabulated and diagrammed records of quantities of materials in bridges given in this treatise. To this extent the author's work may, perhaps, be claimed to be incomplete; but as it is necessary at times for an engineer to make a hurried estimate of cost of a proposed reinforced-concrete arch bridge, some means of ascertaining, at least approximately, the quantities in piers and abutments is a necessity. Hence the author will record here a few data based upon a function that he has evolved and has termed the "Volume of Layout," which consists of the product of the area of the profile (measured vertically between the grade of the floor and the periphery formed by connecting with right lines the lowest parts of adjacent pier foundations, and horizontally between the inner faces of the abutments) by the width of the deck.

In Table 56a are recorded for seven reinforced-concrete arch bridges the following functions: Length in feet of structure between inner faces of abutments; clear width of deck in feet; average height in feet of all the piers and the abutments; average live load, including impact, in

TABLE 56a

Data for Piers and Abutments of Reinforced-Concrete Arch-Bridges

Name of Structure	Length in Feet from Face to Face of Abutments L	Clear Width of Deck, in Feet B	Average Height of Piers and Abutments in Feet H	Average Live Load per Sq. Ft. in Lbs. Impact Included W	Average-Max. Pressure per Sq. Ft. in Tons on the Foundations I	Average of All Ratios of Rise to Span Length R	Average for All Piers of Ratios (> 1) of Adjacent Span Lengths R'	Average Clear Span in Feet S	Average Height of Point of Application of Thrust Above Base T	Number of Spans N	Approximate Area in Sq. Ft. from Bases of Foundations to Grade A	Volume of Layout in Cu. Yds. V	Total Volume of Concrete in All Piers and One Abutment in Cu. Yds. V'	Volumetric Percentage of Total $P = \frac{V'}{V}$	Corrected Value of Preceding Percentage P'	Remarks
Arroyo Seco Bridge, Pasadena, Cal.	1,310	38	76	130	5.2	0.44	1.56	111	11	11	90,560	140,120	3,930	2.81	3.1	Light and very economic structure. Cantilever brackets. Ribbed arches. No abutments included, except in P' column.
Colorado River Bridge, Austin, Tex.	942	48	62	165	16.0	0.16	1.00	111	40	8	58,400	103,900	7,700	7.4	6.0	Economic design. Cantilever brackets. Solid barrelled arches. Expensive substructure. Abutments 50 per cent. larger than piers.
Design for Bridge at Lafayette, Ind.	710	56	61	90	4.8	0.155	1.00	135	38	5	43,310	89,830	6,860	7.64	7.93	Cantilever brackets. Solid-barrelled arches. Abutments about same volume as piers. Structure not built.
Design for Swope Park Bridge, Kansas City, Mo.	580	60	78	120	7.2	0.21	1.33	100	53	5	45,240	100,530	7,200	7.16	7.2	Massive piers. Deep foundations. Cantilever brackets. Ribbed arches. Springing points directly opposite. Structure about to be built.
Arkansas R. Bridge, Tulsa, Okla.	1,400	38	42	130	12.0	0.136	1.00	71	24	18	58,800	82,760	4,860	5.9	5.2	Cantilever brackets. Solid-barrelled arches. Abutments 20 per cent. larger than piers. Structure contains two abutment piers.
Fifth St. Bridge, Dayton, O.	611	57	43	170	6.0	0.10	1.00	81	33	7	26,270	55,470	7,150	12.90	12.2	No cantilever brackets. Solid-barrelled arches, earth filled. Expensive ice-breaks. Abutments 42 per cent. larger than piers.
Webster St. Bridge, Dayton, O.	351	57	38	170	5.5	0.112	1.00	111	26	3	13,340	28,160	3,340	11.84	11.1	No cantilever brackets. Solid-barrelled arches; earth filled. Expensive ice-breaks. Rather large abutments.

pounds per square foot of floor; average maximum pressure in tons per square foot of foundation; average of all the ratios of rise to span-length in the arches; average for all piers of the ratios, greater than unity, of adjacent clear span-lengths; average of all the said clear span-lengths; average of the vertical distances in the various piers between the base and the point of application on the vertical axis of the resultant arch-thrust; number of spans in structure; approximate area in square feet of the surface bounded by the grade line of floor, the periphery of base-bottoms, and the inner faces of abutments; the "Volume of the Layout" in cubic yards found by multiplying the last-mentioned area by the clear width of floor; the total volume of concrete in all the piers and one (average) abutment; the percentage which this last quantity is of the "Volume of Layout"; and the same percentage corrected so as to agree with the assumption that the volume of the one abutment included is equal to the average volume of all the piers. In the last column are inserted some general remarks recording various special features of the different structures. Attention is called to the fact that in the Tulsa Bridge the correction of percentage covers the exclusion of the two abutment-piers, so as to place the record for this structure on the same plane as for the others. The functions of these abutment-piers are to prevent a total collapse of the entire bridge in case of a washout of any pier, and to provide for the possible future construction of a movable span. Their adoption for very long structures where a washout is possible is a wise precaution; nevertheless, one should not, on account of having used them, take any chances by neglecting to make each pier and each abutment just as secure as is practicable against being undermined.

The method of employing Table 56*a* for any particular case is as follows:

First. Prepare a true-scale profile of the crossing, showing the grade line, the ground line, and the inner faces of the abutments; then mark on it a foundation line, indicating, as well as can be anticipated, the depths to which the piers and abutments must go.

Second. Calculate roughly the area included between the grade, the foundation profile, and the face lines of abutments, and multiply it by the clear width of roadway, so as to obtain the "Volume of Layout," v.

Third. Determine which of the seven bridges in Table 56*a* has conditions most nearly agreeing with the one in question in respect to general character of construction, and take its recorded value of P', then multiply together the values of v and P' thus found and divide the product by one hundred. The result will be the total volume in cubic yards for all the piers and one abutment that has the same volume as the average of the volumes of all the piers. If there be two such abutments, the result found is to be multiplied by the ratio $\frac{n+1}{n}$, where n is the number of spans in the proposed bridge. If the abutments are materially different

in size from the average pier, the volume for all the piers alone is to be determined by multiplying the result found by the ratio $\frac{n-1}{n}$; and to this must be added the volumes for the two abutments, which can be arrived at approximately, as explained later.

Fourth. Should there be any abutment-piers in the structure, each such pier will usually have about twice the volume of the average ordinary pier; hence if there are n' such abutment-piers, the value of $\frac{vP'}{100}$ previously found must be multiplied by the ratio $\frac{n+n'}{n}$ in order to determine the volume of concrete in all the piers and one similar-sized abutment.

The relative volumes of piers and abutments for the various heights are by no means constant; because much will depend upon the natural

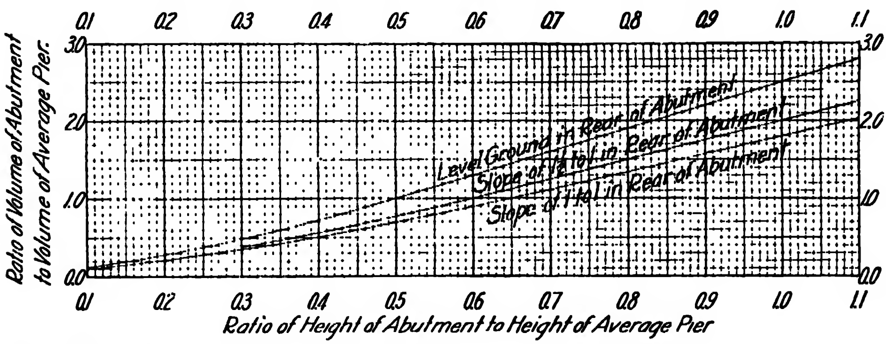


FIG. 56*ee*. Reinforced-Concrete Arch Bridges, Approximate Ratios of Volumes of Abutments and Average Piers.

slopes of the ground in the rear of the latter. For piers and abutments of equal heights and a slope of one and a half to one, the abutment will have about twice the volume of the pier; while if the ground be level, it will have fully two and a half times as much. For piers and abutments of equal volume, the height of the abutment will be about sixty (60) per cent of that of the pier when the rear slope of the ground is one and a half to one, and about fifty (50) per cent when it is level. In order to facilitate the computation of the approximate volumes of the abutments, Fig. 56*ee* has been prepared. In using it one should not forget that it is, of necessity, merely roughly approximate, but sufficiently accurate, however, for preliminary estimates.

The preceding instructions relate to any crossing for which no definite layout of piers and arches has been made. After these features of the proposed structure have been settled, a more accurate estimate of the total volume of substructure concrete can be obtained by modifying the value of P' adopted from Table 56*a* before multiplying it into $\frac{v}{100}$. The said

percentage (P') will vary with the different values of H, W, I, R, R', S, and T, approximately in the proportions given in the following equations, in which the capital letters refer to the known structure of Table 56*a*, and the small letters to the proposed structure:

Height

The percentage p' for a change in height is given approximately by the equation,

$$p' = P' \left(\frac{h}{H}\right)^{\frac{1}{4}} \qquad \text{[Eq. 2]}$$

Live Load

As the dead load does not increase quite as rapidly as the live load and as the section of the pier does not increase as rapidly as the total load upon it, the value of p' for a change in the live load can be taken as

$$p' = P' \left(\frac{w}{W}\right)^{\frac{5}{8}} \qquad \text{[Eq. 3]}$$

Intensity of Pressure on Foundations

As it is only the base of the pier which is affected by the soil resistance, the value of p' with changing foundation loading will be, for average cases, about as given thus,

$$p' = P' \left(\frac{I}{i}\right)^{\frac{1}{3}}. \qquad \text{[Eq. 4]}$$

Ratio of Rise to Span-Length

It is difficult to say how the change in the average ratio of rise to span-length will affect the volume of the piers, but the author believes that the following equation will provide fairly well for the effect of the variation:

$$p' = P' \left(\frac{R}{r}\right)^{\frac{1}{3}}. \qquad \text{[Eq. 5]}$$

Inequality of Adjoining Span-Lengths

The effect of this factor will depend on the relation of the springings of the two spans on each pier. If these be kept at the same height, the value of p' will be given approximately by the equation,

$$p' = P' \frac{r'}{R'}; \qquad \text{[Eq. 6]}$$

while if they are adjusted to equalize as far as possible the pressures on the base, the said value can be taken from the formula,

$$p' = P'\left(\frac{r'}{R'}\right)^{\frac{1}{3}}. \qquad \text{[Eq. 7]}$$

If one of these conditions holds for one structure, and the other condition for the other structure, r' will appear as the first power and R' as the one-third power, or *vice versa*.

Average Clear Span-Length

For any layout, the total volume of piers and abutments will vary with the average length of clear opening adopted, but not very rapidly,

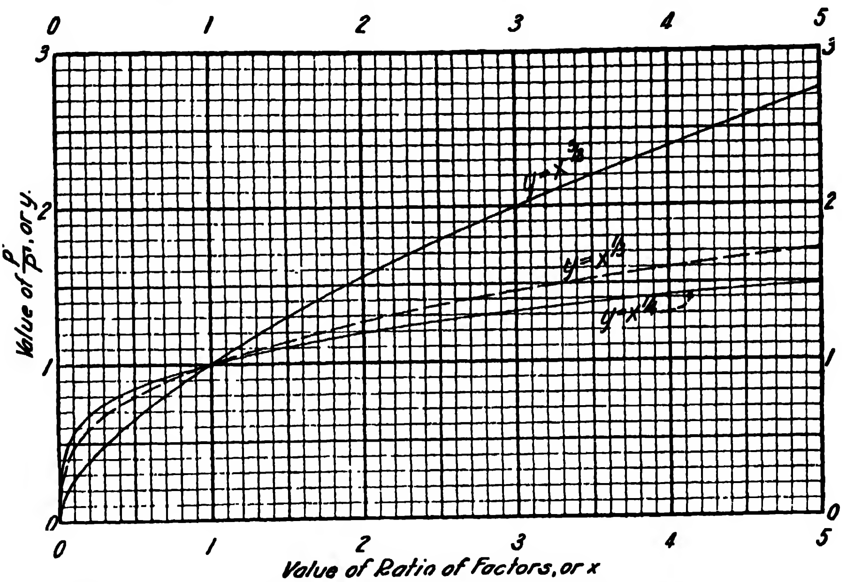


FIG. 56*ff*. Reinforced-Concrete Arch Bridges, Exponential Curves for Reduction Equations.

however; because for a greater span-length the number of piers is decreased, but the volume per pier is increased. The effect of variation will be given with sufficient exactness by the equation,

$$p' = P'\left(\frac{S}{s}\right)^{\frac{1}{3}}. \qquad \text{[Eq. 8]}$$

Average of Lever Arms of Resultant Thrusts

Provided that there be not too great a difference between the values of t and T, the effect of their variation will be given with sufficient accuracy by the equation.

$$p' = P'\left(\frac{t}{T}\right)^{\frac{1}{3}}. \qquad \text{[Eq. 9]}$$

It seems almost unnecessary to state that the product of all the ratios of $\frac{p'}{P'}$, given by Equations 2 to 9 inclusive, will be the final factor with which to multiply the value of P' taken from Table 56a.

In order to determine readily the values of $\frac{p'}{P'}$ in Equations 2 to 9 inclusive, Fig. 56*ff* has been prepared Entering the diagram at the bottom with the ratio of the factors under consideration and tracing vertically upward to the curve representing the exponent of this ratio, the said value is read at the left-hand margin.

It is to be regretted that there are not more examples of the different types of reinforced-concrete arch-bridges recorded in Table 56*a*. For instance, there are not enough records to indicate how the value of P' would change in passing from structures with cantilevered floors to those without them. The author is of the opinion that if the length of any pier is increased by this change m per cent, the value of P' should be increased $\frac{m}{2}$ per cent. Again, in passing from arch bridges without earth-filling to those with earth-filling, exclusive of the effect of omitting the cantilever brackets, there is an increase in the value of P' because of the augmented dead load—possibly from twenty (20) to thirty (30) per cent. Once more, other things being equal, there is an increase in the value of P' due to passing from ribbed to solid-barrelled arches, ranging in amount from about twenty-five (25) to nearly fifty (50) per cent. On account of these great variations it is expedient when using Table 56*a* to adhere as closely as possible to the type of structure contemplated, irrespective of how great may be the variations in the terms of Equations 2 to 9, inclusive; because all the said equations give fairly accurate results even when the values of the corresponding terms are widely divergent.

In respect to what is the proper amount of reinforcing steel per cubic yard of concrete to allow for the piers and abutments of reinforced-concrete arch-bridges, there is a very wide range, depending mainly on the lightness or the massiveness of the construction, the lighter the work the greater being the proportionate quantity of the metal. For piers supporting solid-barrelled arches, twenty (20) pounds per cubic yard will be ample, while for ribbed arches, the steel should be taken at from thirty (30) to ninety (90) pounds per cubic yard, with an average of about sixty (60) pounds. The lower of these values should be used for massive construction, while the upper one should be adopted for light work in which the sections have to be well reinforced for bending. The steel in abutments will vary from twenty (20) to seventy (70) pounds per cubic yard. For mass-abutments with small wing walls, the lower value should be used; while for the same type of abutment with large reinforced wing walls having from one-quarter to one-half of the volume of the said abutments

themselves, from thirty (30) to fifty (50) pounds should be assumed. For crib-abutments about seventy (70) pounds per cubic yard will be necessary.

The preceding method of finding the volumes of piers and abutments can be made applicable by any consulting engineer, in regard to structures designed by his special specifications and according to his individual notions of construction and detailing, by analyzing the records of some of his designs and preparing therefrom a table similar to Table 56*a*; and in applying the corrections for the values of P' in order to obtain close results, he can either use Equations 2 to 9 inclusive, of this chapter, or else he can prepare similar but slightly different equations that will harmonize better with his individual ideas of the methods of volume variation.

As the author has never yet had occasion to design a reinforced-concrete steam-railway bridge, he is unable to give here any data in regard to such structures; but it is perfectly practicable to record all the quantities of concrete for them in exactly the same way as herein explained for highway bridges and combined highway-and-electric-railway bridges of reinforced-concrete construction, and to use the record in the manner described. As soon as a sufficient number of reinforced-concrete railroad bridges have been built to provide a table of adequate size and scope similar to Table 56*a*, analyses of the designing records of such structures should be made and published for the benefit of the engineering profession in general. This would be a good task for some professor of engineering who specializes in bridgework; and it is almost certain that he would meet with no difficulty in collecting the necessary data from the bridge specialists and the railroad engineers.

In order to show how to apply Table 56*a* and Equations 2 to 9, inclusive, to an actual case, an example will now be given.

Let us assume a crossing 1,600 feet long between inner faces of abutments, a clear width between hand-rails of 50 feet, an average height of piers and abutments equal to 75 feet, a live load (including impact) of 140 pounds per square foot, an intensity of pressure on foundations of 5 tons, an average ratio of rise to span of 0.2, an average of all the ratios of adjacent span lengths equal to 1.2, an average clear span of 125 feet, and an average lever arm for thrust equal to 45 feet, the number of spans being twelve; also that there are cantilever brackets, that the arch is solid-barrelled (but without earth fill), and that the heights of the abutments are 65 feet and 25 feet, with a slope of earth about one and a half to one behind the smaller abutment and one that is nearly level behind the larger.

The approximate area of layout is $1600 \times 75 = 120{,}000$ sq. ft., and the "Volume of Layout" is $120{,}000 \times 50 \div 27 = 222{,}200$ cu. yds. The structure in Table 56*a* most nearly resembling the one proposed is the Austin Bridge, for which the value of P' is 6.0.

Substituting in Equations 2 to 8, inclusive, gives the following factors:

$$\frac{p'}{P'} = \left(\frac{75}{62}\right)^{\frac{1}{4}} = 1.05$$

$$\frac{p'}{P'} = \left(\frac{140}{165}\right)^{\frac{5}{8}} = 0.90$$

$$\frac{p'}{P'} = \left(\frac{16.0}{5}\right)^{\frac{1}{3}} = 1.49$$

$$\frac{p'}{P'} = \left(\frac{0.16}{0.20}\right)^{\frac{1}{3}} = 0.93$$

$$\frac{p'}{P'} = \left(\frac{1.2}{1.0}\right)^{\frac{1}{3}} = 1.07$$

$$\frac{p'}{P'} = \left(\frac{111}{125}\right)^{\frac{1}{3}} = 0.97$$

$$\frac{p'}{P'} = \left(\frac{45}{40}\right)^{\frac{1}{3}} = 1.04$$

Multiplying these values together we have

$$p' = 1.415\,P' = 1.415 \times 6.0 = 8.49$$

$$\therefore v' = 222{,}200 \times 8.49 \div 100 = 18{,}900 \text{ cu. yds.}$$

On account of the irregularity of both abutments, this amount has to be multiplied by $\frac{12-1}{12}$ in order to find the contents of the eleven piers alone, making

$$18{,}900 \times \frac{11}{12} = 17{,}300 \text{ cu. yds., or } 1{,}580 \text{ cu. yds. per pier.}$$

The ratios of heights of abutments and average pier are $\frac{65}{75} = 0.87$ and $\frac{25}{75} = 0.33$. Referring to Fig. 56*ce*, we find for the large abutment a ratio of 2.1 and for the small one a ratio of 0.44, making a total of 2.54 for the two abutments; hence their combined volume is

$$1{,}580 \times 2.54 = 4{,}010 \text{ cu. yds.}$$

Adding this to the 17,300 cubic yards found for the eleven piers makes a grand total of

$$21{,}310 \text{ cu. yds.}$$

This chapter was the last one of the book to be completed, because the quantities of materials for reinforced-concrete bridges were not figured until after the MS. of all the other chapters had gone to press; and this question of quantities for piers and abutments was the last one of all to be solved. It had been considered not only by all of his assistants, but also

by the author himself to be absolutely impossible to prepare any diagram, combination of diagrams, table, rule, or formula for determining the said quantities, even with an exceedingly liberal allowance for variation from correctness; but at the last moment he evolved the method herein given.

It is specially hoped that the diagrams of Figs. 56*t* to 56*ff*, inclusive, and the directions for determining approximately the quantities in the piers and abutments of reinforced-concrete bridges will be found truly useful by the engineering profession. In the author's opinion, they are sufficiently accurate for making preliminary estimates of cost; but bidding figures on concrete bridges should never be considered safe unless they are prepared from thoroughly made special computations and sketch drawings. The curves and formulæ, however, should be found serviceable in obtaining an approximate check on the accuracy of all the quantities that have been computed in detail for contractors' bidding figures.

Considering the fact that the establishing of fairly accurate data for making quick estimates for reinforced concrete bridges has, during the last decade, been a dream of the author's (occasionally claimed by some of his friends to be merely a pipe dream), and that, almost without exception, every engineer whom he has consulted about the practicability of preparing such data has declared the task to be impossible of accomplishment, in thus completing the MS. of his book he experiences deep satisfaction in having finally solved the problem (and especially that portion of it relating to the piers and abutments)—at least to his own contentment.

In concluding this chapter, the author desires to tender to Messrs. Harrington, Howard, and Ash, his former partner and associated engineers, his thanks for their courtesy in furnishing him the data for the Tulsa Bridge and the two Dayton bridges recorded in Table 56*a*.

CHAPTER LVII

ESTIMATES

THE making of estimates is one of the most important functions of the bridge engineer, for it is generally the first step that he has to take in connection with any engineering project. Upon his ability to prepare a correct estimate will often depend the important question of whether the projected work is to materialize; and unless he have an established reputation for accuracy, he will not often be entrusted with the making of preliminary estimates for important projects.

The requisites for preparing accurate estimates are as follows:

First. A wide experience in construction and in the actual supervision thereof.

Second. The habit of keeping in touch, through the technical press and otherwise, with the current prices of all materials and labor that are used on engineering works.

Third. The ability to grasp great problems, to follow mentally in advance their entire development and every probable detail of the construction, and to foresee eventualities.

Fourth. The habit of general accuracy and of checking and counter-checking one's computations so as to avoid all errors of magnitude.

Fifth. The faculty of systemization, so as to avoid the possibility of omission of important items of expense by the preparation of lists and the making of records.

Sixth. Absolute honesty, developed to such an extent that the desire to materialize the project will in no way influence the mind to minimize the estimated expense or to omit any probable item thereof.

Seventh. Good judgment to prevent a too honest intention or timidity from overloading the estimate and thus killing the enterprise at the outset.

Eighth. The courage of one's convictions, in order to be able to endorse every estimate unhesitatingly and unequivocally and thus to compel clients to have confidence in the ability of their engineer.

A good fundamental rule for the preparation of any estimate is not to try to round out to too great an extent each item of expense, or to increase it for contingencies, but to add a general item of contingencies at the end. Of course, one should not record the result of the calculations for any item with ridiculous accuracy, because that would shake the client's confidence in the business ability of his engineer; but it is easy enough to use round figures for each item without making it include any contingent allowance. This can be accomplished by diminishing as well as by augmenting the

computed figures for the various items, striking an average for plusses and minuses so that the summation will reduce the resultant error to very small dimensions. If one adds a contingent amount to each item, he is liable to deceive himself in the summation by overloading the estimate; moreover, laymen like to see something added to an estimate to cover contingencies, and they would very properly look askance at any estimate not containing such an item of expense. However, if the contingency amount be made too great, the reader of the estimate will think that the engineer did not know his business, and that he was trying to cover his ignorance by a large allowance for the cost of the unknown. What percentage should properly be added to an estimate for contingencies will depend entirely upon the character of the construction and the probable difficulties to be encountered. For instance, in the case of a viaduct over a dry gorge in a well populated district where there are ample facilities for transportation and where the labor problem cuts no figure, the contingency allowance should be small—perhaps as low as two or three per cent; but in the case of a bridge over a deep and rapid river, with foundations far below the river-bed and at a place distant from civilization, it should be high, say from five to ten per cent. The author considers the latter figure to be the extreme limit for contingencies in good engineering practice; for any larger amount would indicate either that the engineer had not the proper data or that he was timid or inexperienced. The experienced engineer will not determine the amount to add for contingencies by either guess-work or snap-judgment; but will go through his entire list of items of cost and will consider each item separately, so as to decide whether it contains an element of uncertainty, and, if so, about how much should be allowed therefor, summing up all such allowances and perhaps adding a trifle for the absolutely unknown in order to obtain the general item.

The following is a list of items of expense that will aid one in figuring the total cost of any bridge project. It is as complete as the author can make it, nevertheless he would be loth to guarantee that it contains every possible item for any case that may arise. It is understood that no particular project will require all of these items.

Preliminary Expenses

1. Organization of the company, including lawyers' fees, state charges, and all small expenses such as typewriting.

2. Preliminary surveys and the plotting of the data accumulated therefrom.

3. All other preliminary engineering work.

4. Obtaining approval of plans by the War Department.

5. Drafting of complete detail plans and the specifications preparatory to construction.

6. All expenses connected with raising the money to build the proposed structure.

Substructure Construction

1. Mass of cribs and caissons in place.
2. Mass of pedestals in place.
3. Foundation piles in place.
4. Concrete or masonry in shafts of piers, pedestals, and abutments.
5. Coping stones for piers, pedestals, and abutments.
6. Steel or stone protection for piers against ice.
7. Steel shells for piers.
8. Rip-rap for piers and abutments.
9. Mattress work for pier protection.
10. Earth and rock excavation.
11. Back filling.
12. Reinforcing metal for concrete.
13. Removal of old bridge.

Superstructure Construction

1. Superstructure metal delivered at site.
2. Floor timber delivered at site.
3. Rails and their attachments delivered at site.
4. Hand-rails delivered at site.
5. Falsework.
6. Maintenace of traffic.
7. Erection of metalwork.
8. Painting of metalwork.
9. Framing and placing of timber.
10. Laying of rails.
11. Pavement, including base therefor.
12. Operating machinery of all kinds.
13. Machinery house and shelter house.
14. Electric lighting.
15. Counter-weights.
16. Toll house.
17. Concrete.
18. Reinforcing metal for concrete.

Approaches

1. Clearing and grubbing of right of way.
2. Earthwork, including ditches and off-take drains.
3. Track on embankment, including ballast.
4. Frogs, crossings, switches, and signals.
5. Interlocking apparatus.
6. Culverts and tile drains.

Protection Works

1. Mattress work.
2. Dykes.
3. Draw protection or fenders.
4. Cluster piles and their chains.
5. Booms.
6. Lights.

General Expenses

1. Interest during construction.
2. Legal expenses.
3. Right of way.
4. Property damages.
5. Engineering.
6. Rent of offices and other buildings.
7. Travelling expenses.
8. Salaries of administrative officers and all other similar expenses, excluding engineering.
9. Supplies of all kinds.
10. Insurance against accident and fire.

As an example of how approximate estimates of cost should be prepared, the author offers the following example from his practice. In May, 1907, he was called in by Mr. Edward C. Crow, formerly Attorney-General for the State of Missouri, to give evidence in a lawsuit as to what it would then cost to replace the Eads and the Merchants' bridges of St. Louis with structures designed to carry modern live loads. Before giving his evidence he prepared a report embodying the estimates required, and this was received without question or comment by the attorneys. The following is a verbatim copy of the said report:

"Edward C. Crow, Esq.,
St. Louis, Mo.
Dear Sir:

On the 15th inst. you requested me to prepare for you as accurate estimates as possible of what it would cost to replace the Eads and the Merchants' bridges with modern structures designed to carry modern live loads of the same general character as those supported by the existing structures, and using current prices of materials and labor. In the case of the Eads bridge, you preferred to have me figure on simple spans rather than upon arches like those of the present structure; and you desired me not to employ any timber trestle but to adopt instead either steel trestle or earth embankment. In other words, you wish me to estimate on permanent construction.

Immediately after receiving your instructions I procured a small scale plan and profile of each of the bridges, then made a personal examination of the Eads bridge and its approaches, and concluded arrangements to have made for me the next day and sent by wire the necessary measurements of the approaches to the Merchants' bridge. As I possess a copy of Woodward's book on "The St. Louis Bridge," and as years ago I was interested in the preparation of one of the competitive plans for the Merchants' bridge, I soon accumulated ample data for preparing the required estimates. Moreover, as

you know, my firm has lately made a number of estimates of cost for the proposed "Free Bridge" at both Cass and Chouteau avenues, consequently we have at hand all the latest schedule prices for the materials that would enter into the construction of Mississippi River bridges at St. Louis.

The live loads adopted for the estimates were taken from the specifications of my *De Pontibus*, Class R being used for the railway floor, Class B for the wagon floor, and Class C for the footwalks. For the street railway floor system a continuous line of eighty-thousand (80,000)-pound cars on each track was employed. For the trusses there was adopted a combination of a Class U load on each railway track, with street railway cars, heavy vehicular traffic, and pedestrians on the other floors. The entire area covered by the roadways and the street car tracks (including the spaces between the trusses) and the sidewalk areas were assumed to be floored with steel buckled plate covered with a thin layer of asphaltic concrete, on which rest the wooden paving blocks and the asphalt sidewalks. In case of doubt about the exact cost of any work, I have been liberal in my assumption—for instance, in figuring the cost of embankments, not knowing where the earth could be procured, I have allowed forty (40) cents per cubic yard, although thirty-five (35) cents would probably suffice.

The most important of the schedule rates that I have used are the following:

Carbon steel superstructure for river spans erected and painted, four and three-quarters cents (4.75c) per pound.

Ditto for steel approaches, three and eight-tenths cents (3.8c) per pound.

Railway wooden floor and rails, four dollars ($4) per lineal foot of single track.

Creosoted block pavement for roadways, two dollars ($2) per square yard.

Asphalt pavement for sidewalks one dollar ($1) per square yard.

Mass of cribs and caissons of piers in place, eighteen dollars ($18) per cubic yard.

Concrete shafts of piers in place, twelve dollars ($12) per cubic yard.

Limestone facing stones in place, twenty dollars ($20) per cubic yard.

Granite coping stones in place, thirty dollars ($30) per cubic yard.

Excavation for pedestals, fifty cents (50c) per cubic yard.

Concrete for pedestals, eight dollars ($8) per cubic yard.

Piles in place, sixty cents (60c) per lineal foot.

Earth embankment, forty cents (40c) per cubic yard.

Railway track on embankment, including ballast, four dollars ($4) per lineal foot of single track.

For the cost of shore protection, right-of-way, and property damages, not having any data, I had to use my judgment; but I believe I have been liberal in making allowances for these items.

Please note that in estimating the cost of right-of-way I assumed values approximating to those existing at the dates when the bridges were built, and not those ruling to-day; as this appears to me to be the fairest practicable assumption.

The cost of engineering I took at the standard rate of five (5) per cent of the total cost of completed structure; and I made an equal allowance for the cost of financing, interest during construction, and administration.

On the preceding basis my estimates of total cost are as follows:

EADS BRIDGE

One 550′ span at $760 per lin. ft.	$418,000
Two 534′ spans at $745 per lin. ft.	795,660
Two 237′ spans at $470 per lin. ft.	222,780
Pier No. 1	11,000
Pier No. 2	49,000
Pier No. 3	110,000
Pier No. 4	141,000
Pier No. 5	133,000

Pier No. 6	51,000
Combined railway and wagon trestle, 1,350′ at $250	337,500
Highway trestle, 1,250′ at $150	187,500
Railway trestle, 1,250′ at $102	127,500
Short span, 50′ at $70	3,500
Four (4) abutments, say	60,000
Embankments, 200,000 cu. yds. at 40c	80,000
Tracks on embankments, 3,200 lin. ft. at $4	12,800
Shore protection, say	25,000
Right of way and property damages, say	100,000
Summation	$2,865,240
Engineering, financing, interest, and administration, 10%	286,524
Grand Total Cost of Structure	$3,151,764

As a check on the preceding total cost, I beg to state that Waddell and Harrington's estimate for the cost of a similar structure at Chouteau Avenue, without any allowance for financing, interest, and administration, was $3,004,000. Adding five (5) per cent for these omitted items would make the total cost about $3,150,000. This is an unusually close coincidence.

MERCHANTS' BRIDGE

Three (3) spans of 517 ft. each at $445 per lin. ft.	$690,195
Piers No. 1 & No. 4 at $65,000 each (average)	130,000
Piers No. 2 & No. 3 at $83,000 each (average)	166,000
Steel trestle, 3,160 lin. ft. at $116 per lin. ft. (average)	366,560
Five (5) short spans and their four (4) pedestals	58,000
Ten (10) abutments	138,000
Earth embankments, 640,000 cu. yds. at 40c	256,000
Track on same, 17,400 lin. ft. at $4	69,600
Shore protection, about	15,000
Right-of-way and property damages, say	50,000
Summation	$1,939,355
Engineering, financing, interest and administration, 10%	193,935
Grand Total Cost of Structure	$2,133,290

As a check on a portion of the preceding figures, I would state that the contractor's price for the three (3) main spans, four (4) main piers, and the eight hundred and fifty (850) feet of steel trestle which was built at the same time as the main spans, was a little less than one million and seventy thousand dollars ($1,070,000). This figure was tendered on the work by the unsuccessful bidder with whom I was then temporarily associated.

The corresponding figure taken from my preceding estimate of cost is one million, eighty-four thousand, seven hundred and ninety-five dollars ($1,084,795).

There is one important point in connection with my figures to which I desire to call your attention, viz., that while, because of the assumption of modern live loads, my estimates of cost of superstructure would be higher than the present values of the existing superstructures; on the other hand, my designs for substructure, while just as good in every particular, are decidedly more economic than those for the existing bridges. These two variations tend to balance each other, hence the close check in the case of the Merchants' bridge.

Very respectfully yours,
J. A. L. WADDELL,
Consulting Engineer."

While it is impossible to give accurate schedule costs of all the materials and labor in bridge construction because of their variation from time to time and on account of the different conditions at different locations, the average figures in Table 57*a*, which are based on the current American prices for 1915, may be of some assistance in making approximate estimates of cost of bridges and their approaches. These figures are not to be used for reinforced concrete bridges, because those constructions are so fundamentally different from all other kinds of bridges as to warrant their receiving a separate treatment in respect to estimating on their cost. On this account the dissertation thereon which follows later has been made somewhat elaborate in respect to detail.

The determination of the unit costs for the various portions of a reinforced concrete structure is quite a difficult matter, owing to the great variation in certain of the most important factors. Accurate values can be gotten only by estimators who are thoroughly familiar with every detail of construction work; but results sufficiently close for preliminary estimates can be secured much more easily. The most satisfactory book on this subject that the author has had occasion to employ is "Concrete Costs," by Taylor and Thompson. While that treatise is best adapted to making estimates of cost of building construction, it will be found of great value for bridges as well. It will be sufficient for an engineer's preliminary estimate to assume the concrete in place in the various portions to cost so much per cubic yard, the steel in place so much per pound, and the handrails so much per lineal foot, the values being taken as accurately as the knowledge of the estimator will permit. Other items, which are not peculiar to reinforced concrete bridges, will also have to be considered. A contractor's estimate, however, should be based upon a detailed study of all of the construction problems involved.

The principal items which enter into the cost of a cubic yard of concrete are excavation, materials, mixing and placing, and falsework and forms. The chief elements of cost for the reinforcing steel are the cost of the steel itself delivered at site and that of bending and placing. Proper allowance must also be made for overhead expenses, incidentals, and profit.

Excavation is frequently charged against the substructure concrete; but it is better practice to estimate it separately, except in the case of large river piers sunk by the pneumatic or by the open-dredging process. Where conditions warrant, excavation should be separated into different classes, as dry, wet, rock, etc., depending upon the nature of the materials to be encountered. The determination of this item of cost is not difficult, provided there is no considerable amount of rock to be removed, which is very seldom the case unless it be badly disintegrated, as it was in the foundations of a number of bridges and trestles of the author's along the Fraser River in British Columbia.

The cost of the materials for a cubic yard of concrete can be easily computed, as soon as the prices of the cement and of the aggregates and

the proportions of the mixture are known. The cost of mixing and placing the concrete, while somewhat variable, is but a small proportion of the total, so that a sufficiently accurate value of this item can be obtained

TABLE 57a—UNIT PRICES FOR ESTIMATING

Items	Least Cost	Greatest Cost	Average Cost
Mass of pneumatic caissons and their cribs, in place	$16 per cu. yd	$22 per cu. yd.	$18 per cu. yd.
Mass of open-dredging caissons and their cribs, in place	$13 per cu. yd.	$19 per cu. yd.	$15 per cu. yd.
Mass of foundations for pile piers and abutments, excluding portions of piles below base	$12 per cu. yd.	$18 per cu. yd.	$14 per cu. yd.
Timber piles below base	35c per lin. ft.	$1 per lin. ft.	50c per lin. ft.
Cut-off ends of piles	10c per lin. ft.	30c per lin. ft.	15c per lin. ft.
Mass of foundations of piers and abutments placed by coffer-dams	$9 per cu. yd.	$17 per cu. yd.	$12 per cu. yd.
Concrete in shafts of piers, pedestals, and abutments	$7 per cu. yd.	$13 per cu. yd.	$9 per cu. yd.
Granitoid	$12 per cu. yd.	$20 per cu. yd.	$15 per cu. yd.
Concrete piles, in place	$1 per lin. ft.	$1.60 per lin. ft.	$1.30 per lin. ft
First class masonry of limestone or sandstone with concrete backing	$11 per cu. yd.	$19 per cu. yd.	$13 per cu. yd.
First class masonry of granite with concrete backing	$15 per cu. yd.	$25 per cu. yd.	$18 per cu. yd.
Granite copings with quarry face, in place	$18 per cu. yd.	$30 per cu. yd.	$22 per cu. yd.
Steel shells in place	4c per lb.	6c per lb.	5c per lb.
Rip-rap in place	$1 per cu. yd.	$4 per cu. yd.	$2 per cu. yd.
Mattress work	12c per sq. ft.	25c per sq. ft.	18c per sq. ft.
Earth excavation for foundations, including back filling	35c per cu. yd.	$1.25 per cu. yd.	60c per cu. yd.
Rock excavation for foundations	$1 per cu. yd.	$5 per cu. yd.	$2 per cu. yd.
Earth embankment	25c per cu. yd.	60c per cu. yd.	45c per cu. yd.
Reinforcing for concrete	$3 per cu. yd.	$5 per cu. yd.	$4 per cu. yd.
Superstructure metal f.o.b. cars Pittsburg	2.0c per lb.	2.6c per lb.	2.3c per lb.
Yellow pine timber delivered at site	$16 per M.	$35 per M.	$25 per M.
Rails of ordinary size f.o.b. cars Pittsburg	$28 per gross ton	$28 per gross ton	$28 per gross ton
Erection of metal, including falsework	0.6c per lb.	2.0c per lb.	1.0c per lb.
Framing and placing of timber	$9 per M.	$15 per M.	$12 per M.
Field painting of metal work, 2 coats, including paint	0.08c per lb.	0.15c per lb.	0.10c per lb.
Laying of track	12c per lin. ft.	20c per lin. ft.	15c per lin. ft.
Reinforced concrete base for pavements	$2 per sq. yd.	$3 per sq. yd.	$2.40 per sq. yd.
Plain concrete paving base on embankments	$1 per cu. yd.	$7 per cu. yd.	$5.50 per cu. yd.
Asphalt pavement, excluding base	$1 per sq. yd.	$1.30 per sq. yd.	$1.10 per sq. yd.
Creosoted block pavement, excluding base	$2 per sq. yd.	$3 per sq. yd.	$2.50 per sq. yd.
Creosoting timber	$16 per M.	$25 per M.	$20 per M.
Waterproofing, 2 ply	5c per sq. ft.	10c per sq. ft.	8c per sq. ft.
Waterproofing, 3 ply	10c per sq. ft.	15c per sq. ft.	12c per sq. ft.
Waterproofing, 3 ply and mastic	15c per sq. ft.	25c per sq. ft.	18c per sq. ft.

without serious difficulty. The cost of the forms and falsework is one of the largest items in a job; and it varies so much in different cases that even reasonably correct results can be reached only by making a complete outline of the method of construction. It is the variability of this item of cost that makes the estimating on reinforced concrete work such a difficult matter.

The cost of steel delivered at the site can be easily determined. The cost of bending and placing it, however, is quite variable; but it is never a large factor in the total cost.

The expense for handrails is largely a matter of form cost, and is influenced greatly by the elaborateness of the design. While quite variable, it usually forms but a small proportion of the total cost of the structure.

The cost of other items will not differ greatly from those for steel structures. Structural and cast metal may run somewhat high, however, unless large amounts are used.

In what follows there will be given notes, tables, and diagrams for use in preparing preliminary estimates.

Figs. 57*a* and 57*b* can be used to find the cost of the materials for a cubic yard of concrete when the costs of the cement and aggregates are known. In making up these figures, the amounts of cement, sand, and broken stone or gravel for one cubic yard of concrete given in Table 57*b* were employed, a barrel of cement being considered to contain four cubic

TABLE 57*b*

AMOUNT OF MATERIALS REQUIRED FOR ONE CUBIC YARD OF CONCRETE

Coarse Aggregate	Broken Stone—45% Voids		Graded Gravel—35% Voids	
Proportions by Parts	1 : 2 : 4	1 : 3 : 5	1 : 2 : 4	1 : 3 : 5
Cement, barrels	1.51	1.16	1.38	1.06
Sand, cubic yards	0.45	0.52	0.41	0.47
Broken stone or gravel, cubic yards	0.89	0.86	0.82	0.79

feet. To utilize these diagrams, it is necessary to enter at the side with the cost of cement per barrel, trace horizontally to the diagonal line for the cost of the sand per cubic yard, then vertically to the diagonal line for the cost of the broken stone or gravel per cubic yard, and then horizontally to the side, where the cost of all the materials per cubic yard of concrete is read directly. The lines to be followed when cement costs $1.50 per barrel, sand 80 cents per cubic yard, and broken stone or gravel $1.20 per cubic yard, are indicated on the figures. These three unit costs represent fair average values for a number of jobs designed by the author's firm, and can be used for preliminary estimates when no prices are at hand. The prevailing price of cement can always be obtained,

however, and it will rarely be advisable to omit looking it up. To this there should be added the freight rate, and also about ten cents per barrel to cover the cost of unloading, etc. The costs of the aggregates are not so important, although they should be obtained when possible.

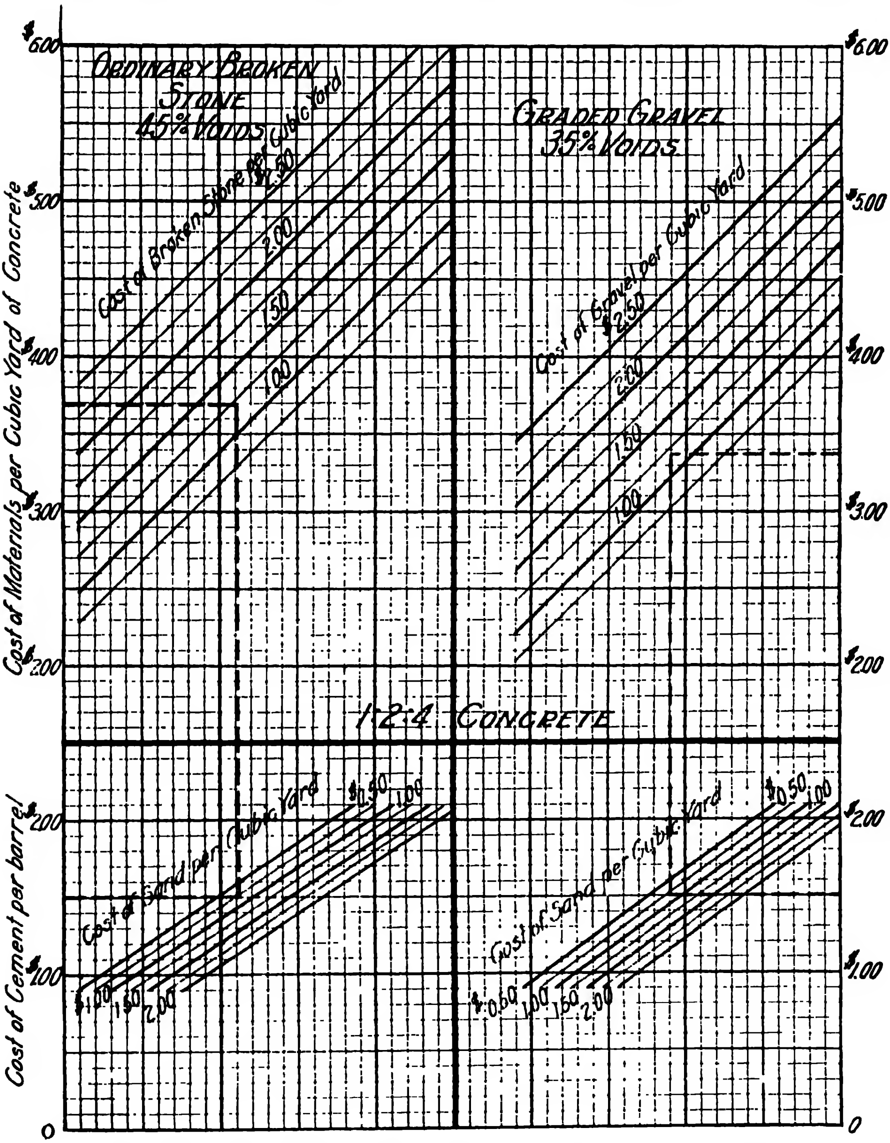


FIG. 57a. Cost of Materials in One Cubic Yard of 1:2:4 Concrete.

If materials have to be handled by wagon for some distance, the prices will have to be increased. Estimates should be made on the assumption that broken stone will be used unless it is known positively that well-graded gravel can be obtained. The curves cover the extreme ranges of

prices of materials that may be expected. Prices of cement are given in *Engineering News* the first of each month.

The cost of mixing and placing concrete will vary in extreme cases from 50 cents to $2.50 per cubic yard. On large jobs (say 10,000 cubic yards)

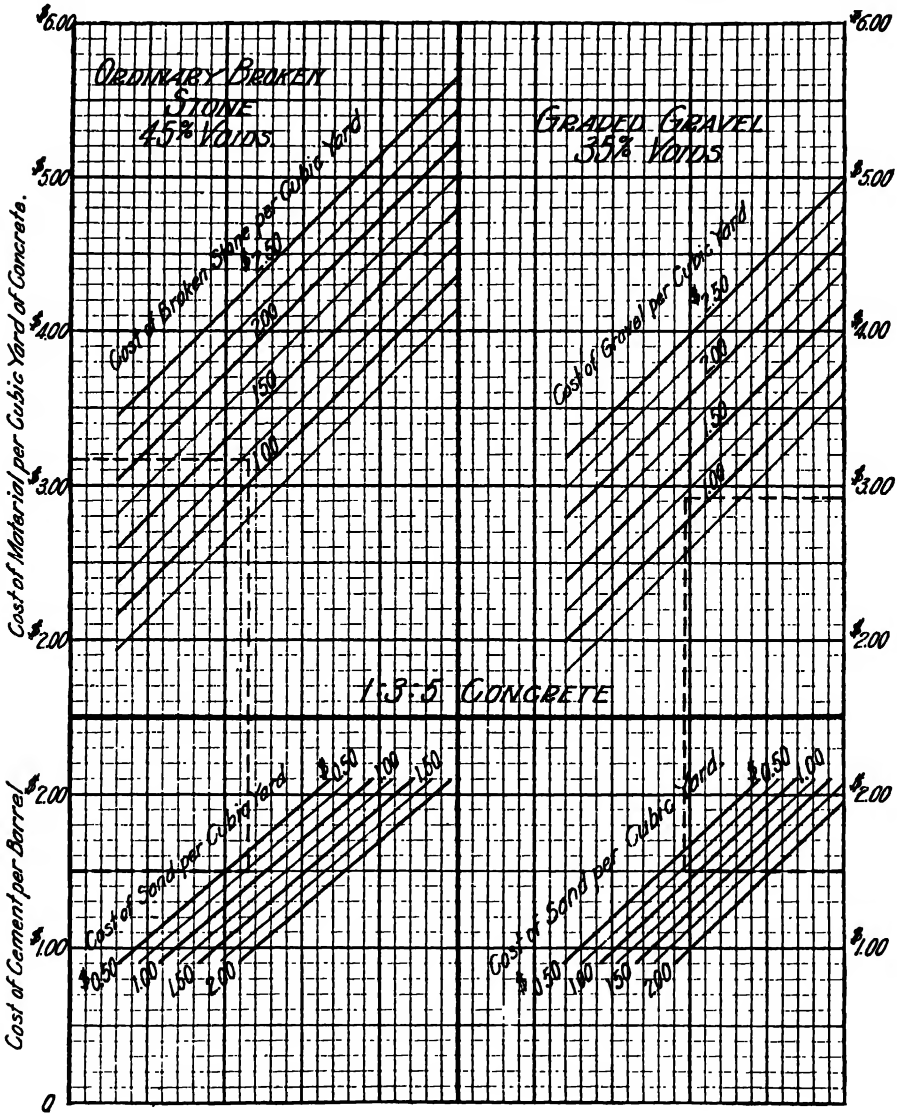


FIG. 57b. Cost of Materials in One Cubic Yard of 1:3:5 Concrete.

under average circumstances it may be expected to run about $1 per cubic yard, and for somewhat smaller jobs $1.50 per cubic yard. For jobs containing less than 1,000 cubic yards the cost may go as high as $2 per cubic yard. These figures include a proper allowance for the cost

of the plant, liability insurance, overhead expenses, and contingencies, but none for profit or wastage.

The costs of forms and falsework are so variable that it is not worth while to attempt to give extended figures therefor. On page 6 of "Concrete Costs" it is stated that the costs of materials and labor for girder bridge forms will run from 5 to 16 cents per square foot of contact area, with an average value of 12 cents. The tables given on pages 7 and 8 of that treatise can be employed to advantage in some cases. These figures, as before, include an allowance for plant, liability insurance, overhead charges, and contingencies, but none for profit.

The cost of reinforcing steel delivered at site on cars or boats is the sum of the price quoted f.o.b. cars at Pittsburg plus the freight rates. The former of these items can be obtained from *Engineering News* the first of each month, and the freight rates to a number of points can be gotten from the same source. Rates to inland points should always be ascertained, as they may run high. It should be noted that small bars cost more per pound than large ones. A fair average price for reinforcing steel delivered is 2 cents per pound for bars ¾ inch in diameter or greater, and 2¼ cents for smaller bars. If the bars must be hauled by wagon for some distance, this fact should be allowed for.

The cost of unloading, storing, bending, and placing reinforcement may be taken at about 0.7 cents per pound as an average. This figure makes an allowance for all overhead expenses, but none for profit or wastage.

The cost of shallow earth excavation in the dry, including that of back-filling, will be about 50 cents per cu. yd. of earth. Deep or under-water work will cost $2 to $3 per cu. yd. of earth removed. Rock excavation will vary from $1 to $3 per cu. yd. of rock removed.

In order to make an allowance for profit, wastage, and home-office expenses, after having provided adequately for all overhead expenses and contingencies, an addition of ten (10) to twenty (20) per cent should be made to the unit costs of both materials and labor. A fair average allowance is fifteen (15) per cent.

In Table 57c are given the maximum, minimum, and average prices for various materials delivered at site, taken from the records of the reinforced concrete bridges which have been designed by the author's firm.

TABLE 57c

COSTS OF MATERIALS FOR REINFORCED CONCRETE STRUCTURES, DELIVERED AT SITE

MATERIAL	Range	Average
Cement, per barrel	$0.90 to 2.10	$1.50
Sand, per cubic yard	0.50 to 1.50	0.80
Broken stone, per cubic yard	0.75 to 2.00	1.20
Gravel, per cubic yard	0.75 to 2.00	1.20
Reinforcing bars, ¾-inch and over, per pound	1.5c to 2.8c	2c
Reinforcing bars, under ¾-inch, per pound	1.6c to 3.05c	2.25c
Structural steel, per pound	2.5c to 4.5c	3.5c
Castings, per pound	2.5c to 5.0c	3.5c

Table 57*d* presents similar information regarding the unit prices paid by his clients for materials in place in completed structures.

TABLE 57*d*

COST OF MATERIALS FOR REINFORCED CONCRETE STRUCTURES, IN PLACE

1:2:4 Concrete Used

	Range	Average
Concrete in pier and column bases, per cu. yd.	\$8.00 to \$11.50	\$9.00
Concrete in pier and column shafts, per cu. yd.	9.00 to 12.00	11.00
Concrete in main girders, per cu. yd.	10.50 to 15.00	13.00
Concrete in cross girders and cantilever beams, per cu. yd.	10.50 to 15.00	13.00
Concrete in fascia girders, etc., per cu. yd.	11.50 to 16.00	14.00
Concrete in slabs, per cu. yd.	9.00 to 15.00	12.50
Concrete in arch rings, per cu. yd.	12.00 to 17.00	13.50
Concrete in stairways, per cu. yd.	15.00 to 30.00	20.00
Concrete in retaining walls, per cu. yd.	9.00 to 15.00	11.50
Handrails on bridge, per lin. ft.	2.00 to 5.00	3.00
Handrails on stairways, per lin. ft.	2.50 to 6.00	3.50
Reinforcing steel, $\frac{3}{4}''$ and over, per lb.	2.5c to 4c	3c
Reinforcing steel, under $\frac{3}{4}''$	2.6c to 4.25c	3.25c
Structural steel, per lb.	4c to 6c	5c
Castings, per lb.	3.5c to 7c	5c
Wrought-iron drain pipes	4c to 8c	6c

The unit prices in this latter table include all expense items of every sort. The corresponding costs of the materials delivered at site are those given in Table 57*c*. The average cost of mixing and placing concrete for these jobs was about \$1.50 per cubic yard, and the average cost of materials in the concrete, by Fig. 57*a*, was about \$3.70, so that the average cost of materials, mixing, and placing was about \$5.20. Adding 15 per cent for profit and wastage, this item becomes \$5.98, say \$6. The average values given in Table 57*d* can be used ordinarily, modified for the differences in the cost of materials. Thus, if for any job cement costs \$1.80 per barrel, sand \$1 per cu. yd., and broken stone \$1.50 per cu. yd., and the cost of mixing and placing is \$2 per cu. yd., the average unit costs for concrete in place should be increased by $1.15\ (4.50 + 2.00) - \$6.00 = \$1.47$ per cu. yd. In a similar manner, if for any job the price of reinforcing steel ¾ inch or larger is 1.25 cents f.o.b. cars at Pittsburg, and the freight rate is 0.30 cents, the cost of the steel in place will be $1.15\ (1.25 + 0.30 + 0.70) = 2.59$ cents.

In preparing preliminary estimates of cost one should be liberal but not extravagant; for clients will readily forgive an inaccuracy by which they save money, but they will remember unfavorably for a long time an engineer whose estimates have been materially exceeded by the actual cost of the work. There are certain allowances for extras that should always be made; for instance, permissible excess in weight of metal, which amounts to from one to three per cent, according to the character of the construction;

loss or destruction of rivets and bolts during erection, amounting to fifteen or twenty per cent; waste of timber from dressing and cut-off ends; and waste of piling from both cut-off ends and injury in driving.

Every estimate made should be carefully checked and counter-checked, preferably by another computer. The errors of most common occurrence are those of omission of items, or from failure to multiply or divide certain figures by two, or the counting in twice of some item of expense by having it included directly and covered also in some other item. These are the errors that count, and they are, unfortunately, the most difficult ones to discover. Errors of arithmetic can be corrected by anyone, but the proper checking of an engineer's estimate can be done only by another engineer.

There is a type of preliminary estimate of a most unsatisfactory character, which, occasionally, a bridge engineer has to make. It is often but little better than a guess, and as such is objectionable to any high-class engineer; but his client generally insists upon his making it in spite of his protests. The reference is to preliminary estimates of cost of bridges based solely on railroad engineers' profiles and the few data they may contain regarding the conditions which would affect the substructure design. In such a case the best way to proceed is to take one crossing at a time, determine as well as possible the best average span length for it based upon the height of the grade and the insufficient substructure data (erring, preferably, on the side of safety in respect to the said length), find from weight curves the corresponding weight of metal per lineal foot for the railway company's standard live load, assume the pound price of the metal erected after taking into consideration all the conditions that would affect it, compute the cost per lineal foot of the superstructure, including the track or tracks and the usual allowance for engineering and inspection, assume that the cost per lineal foot of span for the entire substructure is equal to that for the superstructure (an error which is generally on the side of safety), and add the two together, allowing ten (10) per cent additional for contingencies, or more if the uncertainties involved be greater than usual. The result will probably be about right in most cases, but occasionally it will prove too low after the entire cost of the completed structure has been computed. A not uncommon error in this connection lies in the determination of the total length of structure required, the tendency on the part of the railroad company often being to shorten it unduly. The consulting engineer is sometimes apt to consider the opinion of the company's engineers as infallible, the result being that further investigation of the crossing necessitates a lengthening of the structure. Again, the rock shown on the railroad profile is generally assumed as hard and suitable for foundations, while quite often the reverse proves to be the case. This condition not only adds to the total cost of structure because of the expense for excavating the unsatisfactory material, but also increases the total length of bridge.

The consulting bridge engineer has many other estimates to make than those of first cost; for instance, estimates of the cost of maintenance, renewals, and operation; estimates of revenue; estimates of time required for construction; estimates of how money will be required to pay for work as it proceeds, and the interest thereon up to the anticipated date of completion; and comparative estimates of cost of various methods of construction for any projected work by taking account of the compound interest involved.

In computing the cost of maintenance, renewals, and operation, one should assume a long term of years so as to obtain a proper average, and this length of time should be determined by the probable date of the most important renewals or repairs; for instance, the replacing of track or pavement or the renewal of timber approaches. The following list of items for cost of maintenance, renewals, and operation, while possibly not absolutely complete, will aid one materially in preparing an estimate of this kind.

1. Painting of metal.
2. Renewal of timber floor or pavement.
3. Renewal of handrails.
4. Renewal of timber approaches or the replacing of them by permanent earth embankments.
5. Renewal or repairing of shore protection.
6. Renewal or repairing of draw protection.
7. Repairs to operating machinery
8. Pointing of masonry.
9. Adding of rip-rap.
10. Renewal of track rails.
11. Repairs to lighting apparatus.
12. Fuel, oil, and waste for operating machinery.
13. Fuel for heating.
14. Electric or other lighting.
15. All rents.
16. Salaries of bridge tenders.
17. Salaries of track repairers.
18. Salaries of officers of the bridge company.
19. Salaries of toll collectors.
20. Salary of bookkeeper or accountant.
21. Electric power for operating opening span or for traction.
22. Insurance.
23. Taxes.

The estimating of revenue is often a most difficult matter, for on the one hand there is the almost unavoidable desire to make the best showing possible, and on the other there is the danger of forgetting some item of profit or of failing properly to anticipate future development of traffic. If a highway bridge is contemplated for a crossing where a ferry has been

used hitherto, it is safe to count upon an increase of fifty (50) per cent of the ferry receipts as the probable initial revenue of the bridge. If a street railway is to use the structure, an approximate estimate of the travel thereon should be made by noting the population on each side of the river in the vicinity of the location and learning from investigation of the records of toll bridges similarly situated what the annual travel per inhabitant is likely to be. The influence of the structure on the increase of population should not be forgotten, but this possibility should not be given too great weight. Sometimes a canvass of the people of the vicinity will aid in determining the probable amount of annual travel per inhabitant, per family, or per house; but if the people want the proposed bridge, as is generally the case, the information thus obtained must be taken *cum grano salis*. The consulting engineer must not forget that while the amount of traffic is pretty certain to increase, the toll rates are likely to be diminished, and he must remember that with increased traffic come increased expenses for repairs and renewals.

Possible items of revenue are the carrying of the mails and express. Telegraph, telephone, electric lighting, and power lines, and pipes for water, oil, or gas when carried by a bridge are a source of revenue—not great, it is true, but still well worth considering.

Estimates of the time required for completion and of the amounts of money for monthly payments, as well as of the amount to allow for interest during construction, can be made with a fair degree of accuracy by an engineer who has had wide experience in bridge building and in dealing with contractors. In estimates of this kind due account should be taken of the favorability of time of commencement of field operations, condition of the material and labor markets, and the amount of difficulty that may be expected in doing the work. A good example of an estimate of this kind is given in Chapter LXX, which treats of "Reports."

The same chapter gives also an example of comparative estimates of cost of various proposed structures when compound interest is considered. From it will be seen that the proper method of comparison is the ascertaining of what each structure will have cost after the expiration of a certain term of years, and when all of the structures compared are in like condition as to efficiency and value. Another method of comparison is to reduce all costs to equivalent first costs, sum these up for each case, and compare the results.

The compound interest table given in Table 57e will be found very useful in making comparative estimates of cost of this kind.

With compound interest at 3 per cent, money will double itself in 23½ years, at 4 per cent in 17½ years, at 5 per cent in 14.2 years, and at 6 per cent in 11.9 years.

Up to here, excepting incidentally in the case of reinforced concrete, the subject of "Estimates" has been treated solely from the point of view of the consulting engineer, which should be identical with that of the

railroad engineer, but there are other bridge engineers than consulting ones, and they have estimates to make of a different kind, consequently the remainder of this chapter will be devoted mainly to their needs. The other engineers referred to are those of the bridge manufacturers and erectors; and they outnumber the consulting engineers probably ten to one.

TABLE 57c

COMPOUND INTEREST TABLE

Values of one dollar at compound interest, compounded yearly, at 3, 4, 5 and 6 per cent from 1 to 50 years.

Years	3%	4%	5%	6%
1	1.03	1.04	1.05	1.06
2	1.0609	1.0816	1.1025	1.1236
3	1.0927	1.1249	1.1576	1.1910
4	1.1255	1.1699	1.2155	1.2625
5	1.1593	1.2166	1.2763	1.3382
6	1.1941	1.2653	1.3401	1.4185
7	1.2299	1.3159	1.4071	1.5036
8	1.2668	1.3686	1.4774	1.5938
9	1.3048	1.4233	1.5513	1.6895
10	1.3439	1.4802	1.6289	1.7908
11	1.3842	1.5394	1.7103	1.8983
12	1.4258	1.6010	1.7958	2.0122
13	1.4685	1.6651	1.8856	2.1329
14	1.5126	1.7317	1.9799	2.2609
15	1.5580	1.8009	2.0789	2.3965
16	1.6047	1.8730	2.1829	2.5403
17	1.6528	1.9479	2.2920	2.6928
18	1.7024	2.0258	2.4066	2.8543
19	1.7535	2.1068	2.5269	3.0256
20	1.8061	2.1911	2.6533	3.2071
21	1.8603	2.2787	2.7859	3.3995
22	1.9161	2.3699	2.9252	3.6035
23	1.9736	2.4647	3.0715	3.8197
24	2.0328	2.5633	3.2251	4.0478
25	2.0937	2.6658	3.3864	4.2919
30	2.4272	3.2434	4.3219	5.7435
35	2.8138	3.9460	5.5166	7.6861
40	3.2620	4.8009	7.0100	10.2858
45	3.7815	5.8410	8.9850	13.7646
50	4.3838	7.1064	11.6792	18.4190

The engineer of a bridge manufacturing company is generally called upon to estimate only on the cost of metal delivered at site. In doing this he will find the following list of items of cost to be of service:

1. Materials delivered at shops.
2. Drawings.
3. Templates.
4. Laying out the work.

5. Shearing.
6. Straightening.
7. Punching.
8. Assembling.
9. Reaming.
10. Riveting.
11. Milling.
12. Annealing.
13. Boring.
14. Forging, if any.
15. Casting, if any, including patterns, foundry work, and machining.
16. Painting.
17. Loading.
18. Freight to site.
19. General expense.

The "General Expense" should include the following items:

1. Correspondence.
2. Accounting.
3. Estimating.
4. Designing.
5. Office rental.
6. Light.
7. Heat.
8. Power.
9. Repairs to machinery.
10. Renewals of machinery.
11. Insurance.
12. Taxes.
13. Rent.
14. Interest on money invested.
15. Contracting.
16. Traveling.
17. Office supplies.
18. Unassignable labor (such as yard labor).
19. Errors and defects.
20. Superintendence.

Each manufacturing company has a way of its own for figuring the general expense, consequently in dealing with this matter the author will proceed no farther, for he deems that in offering the preceding list he has penetrated far enough into the private affairs of the manufacturer of bridge metal.

The engineer of the superstructure erector in estimating the probable cost of his work will need to include the following items:

1. All other materials than metal, delivered at site.
2. Freight on equipment both ways.

3. Transportation of men both ways.
4. Unloading of materials.
5. Falsework.
6. Maintenance of traffic.
7. Removal of old structure.
8. Erecting.
9. Riveting.
10. Framing and placing of timber floor.
11. Laying of track.
12. Building of base for pavement.
13. Paving.
14. Cleaning and painting of metalwork.
15. Removal of falsework.
16. Disposal of falsework.
17. Repairs and renewals of equipment.
18. Superintendence.
19. Contingencies.

The engineer of the substructure contractor, preparatory to the bidding, will need to take cognizance of the following items in making estimates of cost:*

General Expense

1. General office expense.
2. Traveling.
3. Interest.
4. Legal expense, local taxes, permits, etc.
5. Employers' Liability insurance
6. Transportation of men, including their time while traveling.
7. Plant rental.
8. Freight on plant—both ways.
9. Unloading and installing plant.
10. Dismantling and reloading plant.
11. Maintenance and repairs of plant.
12. Tools and general supplies.
13. Temporary buildings.
14. Superintendence and local office force.
15. Local office expenses.
16. Camp expenses.
17. Fuel and water.
18. Donations and charities.

* These data for substructure were furnished by Lee Treadwell, Esq., Member of the American Society of Civil Engineers and at the time Vice-President and Engineer of the Union Bridge & Construction Co.

Materials

1. The cost f.o.b. the job of all materials entering directly into the items of the contract.

2. The cost f.o.b. the job of all materials for temporary construction, such as wharves, platforms, staging, forms, shoring, etc.

Labor

1. Unloading and storing materials.
2. Clearing up site.
3. Excavation:
    - *a.* Digging and hoisting out.
    - *b.* Disposing of the excavated material.
    - *c.* Shoring.
    - *d.* Pumping.
    - *e.* Removing shores and back-filling.
4. Pile driving:
    - *a.* Handing and delivering piles to the driver.
    - *b.* Driving the piles.
    - *c.* Sawing off ready for capping.
5. Concrete:
    - *a.* Delivering materials from stock piles into mixer or onto mixing platform.
    - *b.* Mixing the concrete and placing it in wheelbarrows or in buckets.
    - *c.* Handling concrete from mixer and tamping it in place.
    - *d.* Building and removing forms.
    - *e.* Cleaning and pointing up work after forms are removed.
6. Masonry:
    - *a.* Unloading and storing.
    - *b.* Handling from yard to derrick which sets stone.
    - *c.* Labor.
    - *d.* Setting, including mixing mortar.
7. Timber work:
    - *a.* Handling from stock piles.
    - *b.* Framing.
    - *c.* Placing and securing in final position.
8. Pneumatic Caissons.
    - *a.* Building caisson and crib.
    - *b.* Launching and mooring.
    - *c.* Sinking.
    - *d.* Leveling up bed rock.
    - *e.* Concreting working chamber.
    - *f.* Concreting crib.

g. Lighting.
h. Coffer dam and pumping.
i. Building upper shaft of pier.

9. Yard force, keeping up tracks, shifting plant, carrying tools, water boys, and watchmen.

The method of doing the work and that of being paid will influence greatly a contractor's estimated cost of any construction. If he be allowed a free hand as to where to begin and how to carry on the different parts of the work, he will naturally figure lower than when he anticipates interference in such matters. If the pay is to be regular, in cash, and as full as is customary, he will estimate lower than when he fears irregular payments, or when he has to take securities instead of cash, or when the percentage retained till completion is excessive.

If the work to be done is for the Government, the contractor will have to add some fifteen or twenty per cent to his estimates to allow for red tape, guaranteeing of the correctness of the data submitted, slow payments, unnecessarily severe inspection, and the general demoralization of his force by disheartening hindrances. Nor is the Government the only sinner of this kind; for sometimes railroad engineers, and once in a great while a consulting engineer, will make life a burden to the contractor by unnecessarily severe and irresponsible inspection; consequently the task of the contractor's engineer in estimating the probable cost of work is by no means an easy one. Again, he cannot help being influenced by the amount of competition that is anticipated, although he should do his best to banish this thought from his mind before starting to prepare his estimate.

There is another kind of estimate that properly belongs elsewhere, viz., the monthly estimates prepared by resident engineers on construction. It will be considered in Chapter LXI, which treats of the "Engineering of Construction"; but it will be proper to make here a few remarks as to how the resident engineer should be governed in arranging for partial payments to the contractor as the work progresses, for this matter is often left entirely in his hands. In figuring the value of the work done and the materials furnished, the exact net cost to the contractor should not be adopted, but a fair allowance should be made for his general expenses and his profit; because before he is paid there is always a reduction of ten or fifteen per cent made from the amounts of the monthly estimates, which difference is retained until the completion of the entire work. If a good and sufficient bond for the proper completion of the contract has been provided, as it always should be, there is no risk in allowing the contractor fairly full payments on account as the work proceeds. Liberal treatment of this kind will keep all concerned in good humor and will lubricate the wheels of progress.

In conclusion the author offers this suggestion to all engineers in

estimating cost of proposed constructions: "Take every precaution to omit no item of probable expense, compute as accurately as possible the amount for each item without adding to it for contingencies, figure in detail the proper total allowance for contingencies, sum carefully all the items of expense, check and counter-check your figures in every way that you can think of, then stand by the resulting estimate with courage and conviction."

CHAPTER LVIII

OFFICE PRACTICE

Nearly two decades ago, when preparing the manuscript of the last chapter of *De Pontibus*, the author wrote thus:

> "As there has been almost nothing yet written concerning the way in which work is handled in a consulting engineer's office, the author has concluded to close this little treatise with a chapter on 'Office Practice'; and as no two engineers pursue exactly the same methods, and as the author is naturally more familiar with his own than with those of others, he will deal herein solely with the established practice of his own office, which practice is the outcome of over ten years of special effort to secure the best possible results both expeditiously and economically."

The chapter referred to covered the author's personal experience as a bridge specialist up to 1897; but between that date and July, 1915, he has been the senior partner of two consulting bridge engineering firms; and the amount of professional work done has increased greatly, with the consequence that the methods of handling office affairs have had to be modified materially. In the old days it was the author's policy to be on terms of intimacy with all of his employees and to direct personally each one's work, looking himself to every important detail so as to ensure the correctness of everything going out of the office. But after the establishment of the first of the two firms referred to, the amount of business undertaken reached such dimensions that a division of responsibility became necessary; and gradually the handling of the drafting office was entrusted to others so as to leave the author free to attend to the business of the firm, the traveling, the general studies of crossings and layouts, the preparation of specifications, the general supervision of the progress of construction, and the making of periodical visits to the fieldwork. As time passed and as the amount of work undertaken continued to increase, it became necessary for him to share some of these duties also with his partner and the firm's principal assistant engineers; and the redivision of duties and personal responsibilities continued steadily until of late years the author's attention has been devoted mainly to the higher portions of the work, including the dealing with governments both at home and abroad, the making of important technical investigations of a general nature, the preparation of forms and instructions for writing specifications and contracts and for doing other work in both office and field, and attending to a share of the necessary traveling. On this account many of the changes in details of the office practice have been evolved by his partner and the firm's employees; and they are recorded in the discussion which follows:

As the information given in *De Pontibus* was both sound and, for those days at least, thorough, Chapter XXIV of that little treatise has been employed as a basis in writing this one, by reproducing it with the various modifications and additions necessary to bring it up to date. At the risk of being tedious to the reader, there is included a mass of office forms, instructions, records, etc. Only those who are personally interested in office-work need to peruse this collection; and, consequently, it is hoped that the general reader will not be either bored or displeased by the inclusion of such an accumulation of dry material.

Making and Checking Calculations and Drawings

Laying Out Work

This chapter being confined entirely to office-work, it will be assumed at the outset that all such field data as profiles maps plats of borings, etc., have been secured.

In bridgework it is necessary to determine the following:

First. The Purpose for which the Structure is to be Used.—This being settled, there ensues the fixing of the live load, the spacing of trusses or girders, and the clear height above base of rail or surface of roadway.

Second. The Clear Height between Standard High Water and the Lowest Part of Superstructure.—If the stream be a navigable one, the minimum clearance will be regulated by the requirements of the War Department, as explained fully in Chapter L. In other cases the clear height will depend on the required elevation of grade of railroad or roadway, provided that the lowest part of the superstructure will never offer any obstruction to floating ice or drift during the highest floods. The minimum clearance should preferably be ten feet, and never less than five. Where a low bridge is required over a navigable stream, the best type to employ is to be determined as explained in Chapter XXVIII; and the type selected is to be designed in accordance with the information given therein and in one of the three immediately succeeding chapters. Restrictions concerning both vertical and horizontal clearances for railroads and traffic-ways crossed should receive due attention.

Third. Best Span Lengths to Adopt.—In many cases there will be no choice as to span lengths, which are liable to be determined by such conditions as the requirements of the War Department, obstruction of stream by piers, danger from washout during erection, etc.; but, where the designer has any choice in the matter, he should be governed by the principles of economy laid down in Chapter LIII, taking care, however, that he does not violate any of the principles of æsthetics given in Chapter LII, unless he be forced to do so by circumstances that are absolutely beyond his control. As stated in Chapter LIII, in steel bridges the greatest possible economy will exist when the cost of each pier is equal to one-half of the cost of the trusses and lateral systems of the two spans which it helps to

support. The determination of these economic conditions is, of course, a matter of cut-and-try; but after a few trials the economic span length can be approximated very closely. In making such calculations the trial weights of trusses and laterals can be found from Chapter LV. The economic span lengths for reinforced concrete bridges, which are generally more difficult to determine than those in steel structures, are discussed in Chapter LIII; and diagrams giving quantities are to be found in Chapter LVI. In reinforced-concrete arch bridges the span lengths, when not determined by physical conditions, should be settled by general economic principles, including the balancing of thrusts so as to reduce to a minimum the eccentricities of loading on the foundations.

The method of determining the layout is discussed very fully in Chapter LIV; and the determination of the waterway, in Chapter XLIX.

Fourth. General Layout of Structure.—The general layout should consist of a profile, a plan, and enough cross-sections to illustrate properly the entire substructure, superstructure, and approaches, all being made to exact scale. For long crossings, a scale of one-fortieth of an inch to the foot is the most satisfactory, but for short crossings the scale should be made larger. The proportioning of the skeleton of the trusses should be done in accordance with the suggestions given in several of the preceding chapters, and the dimensions of the piers should be determined by the principles established in Chapter XLIII.

Each general layout should give the following information:

Borings, low water, standard high water, extreme high water, lowest part of structure, grade-lines, and tops of piers; lengths of all spans between centres of end-pins or centres of bearings; distances between centres of piers; clear openings for movable spans; vertical clearance above extreme high water for lift spans; and lengths and kinds of approaches.

As soon as the general layout is completed and finally adopted, the computations of stresses and sizes of members of spans may be begun.

For elevated railroads it is necessary to determine the following:

A. The number of tracks on the various portions of the line, and the clearances over streets and alleys.

B. The live load per track to be carried by the structure.

C. The location of the line, whether in the streets or on private property.

D. The style or styles of girder construction. In some locations the city ordinances may require open-webbed girders, as these shut out less light than do solid-plate girders, while in other locations the plate girders would be permissible.

E. The location of columns, whether in the street or on the curbs, also, for location on private property, the number of columns per bent.

F. The economic span length. As indicated in Chapter LIII, the greatest economy will exist when the cost of the longitudinal girders is

equal to the cost of the cross-girders, columns, and pedestals. Where the columns are located in the street or on the curbs, due consideration must be given to the probable cost of removing underground obstructions, such as water-pipes, gas-mains, etc.

G. Where a structure is on a sharp curve it is sometimes advisable to make the bents radial; but, whenever practicable, it is best to make the towers perfectly rectangular and to throw the skew entirely into the intermediate span, so as to simplify and cheapen the shopwork. The exact location of each column should be figured from certain known lines, and all ordinates for the same should be indicated on the layout.

Much careful study should be given to the work of establishing each feature of the layout; for, if mistakes be made therein, they are likely to cause great delay and expense later on. With these points all settled, the calculations for proportioning all parts of the structure may be proceeded with.

Calculations

After the leading features of any proposed structure have been settled, and after the general layout thereof is completed, the next step to take is the making of the calculations necessary to determine the stresses in all the parts and the proper sizes for same. For convenience in making to correct scale pen-sketches of the various portions of the design, the author uses a cross-section paper divided into one-quarter-inch squares, the sheets being ten and a half inches wide by sixteen inches long, which size experience has shown to be the most satisfactory. At the head of each page are written the date, title of structure, and name of computer. This form is shown in Fig. 58*a*.

Each set of calculations is started by filling out all the blanks on a data-sheet of the same size as the calculation sheets, but not ruled into squares. This data-sheet is illustrated in Fig. 58*b*.

Before figuring each truss span there should be recorded for it the following:

First. Length.

Second. Number of panels.

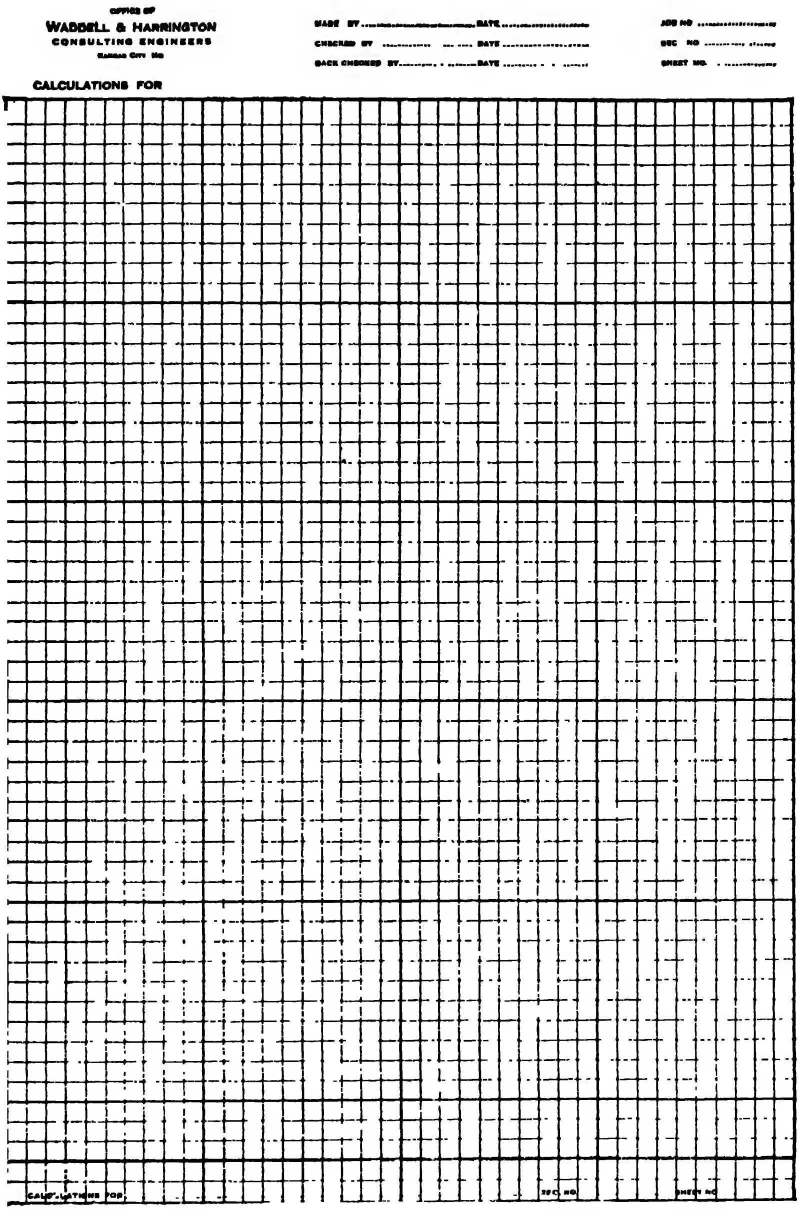
Third. The various truss depths.

Fourth. Perpendicular distance between central planes of trusses.

Fifth. Spacing of stringers.

The dead load from the track and ties in railroad bridges, or from the timber floor or pavement in highway bridges, is first determined, using the unit weights of materials given in Chapter V; then the stringers or longitudinal girders are figured and proportioned, after which their weights and that of their bracing are computed.

Next the floor-beams or cross-girders are proportioned, and their weights are figured. From all these weights the weight per lineal foot of the metal in the floor system is next found.


OFFICE OF
WADDELL & HARRINGTON
CONSULTING ENGINEERS
KANSAS CITY MO
MADE BY .... DATE ....
CHECKED BY .... DATE ....
BACK CHECKED BY .... DATE ....
JOB NO ....
SEC NO ....
SHEET NO ....
CALCULATIONS FOR

CALCULATIONS FOR
SEC NO
SHEET NO

FIG. 58*a*. Calculation Sheet.

OFFICE OF
WADDELL & HARRINGTON
CONSULTING ENGINEERS
KANSAS CITY MO

CALCULATIONS FOR

NAME OF COMPANY OWNER OR CLIENT

OBJECT OR PURPOSE OF THESE CALCULATIONS

GENERAL DESCRIPTION AND DATA

WIDTHS OF ROADWAYS AND SIDEWALKS NUMBER AND SPACING OF TRACKS AND CHARACTER OF LIVE LOAD

SPECIFICATIONS

LIVE LOADS TO BE CARRIED — BY FLOOR SYSTEM — BY TRUSSES

RAILWAY TRACKS

ELECTRIC RY TRACKS

HIGHWAY ROADWAYS

SIDEWALKS

WIND LOADS

FLOORING AND PAVING

GRADES AND ELEVATIONS TOP OF ROADWAY AND BASE OF OF RAIL

ALIGNMENT

CLEARANCES REQUIRED — HORIZONTAL — VERTICAL

FOR RY LOADING

FOR HIGHWAY LOADING

ABOVE HIGH WATER

FOR OVERHEAD CROSSINGS

DISTANCE C TO C TRUSSES

ELEV HIGH WATER

ELEV LOW WATER

REQD CLEAR DISTANCE BETWEEN END PIERS AT RIGHT ANGLES TO STREAM

MOVABLE SPAN CLEAR CHANNEL REQD AT RIGHT ANGLES TO DIRECTION OF CURRENT

VERTICAL CLEARANCE ABOVE H W SPAN CLOSED OR LOWERED

" " " OPEN OR RAISED

TIME REQD TO OPEN OR RAISE SPAN

" CLOSE OR LOWER SPAN

KIND OF POWER AND TYPE OF MECHANICAL EQUIPMENT

TYPE OF HAND RAIL — PAINT

REMARKS

FIG. 58b. Data Sheet for Calculations.

As the lateral system can nearly always be designed before the trusses, it is generally best to compute the weight per lineal foot of the entire lateral system before the trusses are touched, because the dead load for the latter will be affected by the weight of the former.

Next it is necessary to assume the weight of metal per lineal foot for the trusses. This completes the data for the preliminary dead load, which will consist of the following items:

First. Flooring (timber, track, pavement, etc.).

Second. Floor system (stringers, stringer-bracing, and floor-beams).

Third. Lateral system (upper and lower lateral systems, vertical sway-bracing, and portal-bracing).

Fourth. Trusses.

In making up the dead load, the end floor-beams and pedestals must not be included, as their weight produces no bending moment on the span.

The dead-load stresses in trusses are always found analytically for spans with parallel chords and equal panel-lengths; but for other cases they are usually determined graphically, and are checked by a single numerical calculation at the member where the graphics stop, as explained in Chapter X. They are recorded on a skeleton diagram of the truss.

The live-load stresses are found by the method explained in Chapter X, and are recorded on a separate skeleton truss diagram. Whenever it is practicable, in making arithmetical computations, the slide-rule is employed. For ordinary work, in which the total stresses can be written with six figures, a ten-inch slide-rule will give the stresses accurately in thousands of pounds; but where the stresses are greater, Thacher's cylindrical slide-rule can be employed, although the ten-inch slide-rule is generally sufficiently accurate.

The computation of all stresses found analytically is facilitated by determining the trigonometrical functions involved in the calculations, and multiplying the panel loads by them. By setting these products on the slide-rule and using the proper tabulated coefficients—given in Tables 10*b* to 10*i* inclusive—it is often practicable to read off a large series of stresses without resetting the slide.

The impact stresses are found from the live-load stresses by slide-rule, using the diagrams given in Figs. 7*c*, 7*d*, and 7*e*, and are written, preferably, upon a separate skeleton truss diagram; although some computers prefer to record them on the live-load skeleton diagram, each impact stress being placed directly beneath the live-load stress to which it corresponds.

Next are computed all the wind-stresses which could possibly affect the sizes of the sections of main-truss members, and these are recorded either on a separate diagram or on one of those already prepared, in the latter case care being taken to indicate that each such stress is marked as a wind-load stress.

Next the various combinations of all stresses are made and recorded

on a new diagram, after which the required sectional areas of all main members are figured according to the specifications, and are written on the same diagram; then the actual sections are proportioned and recorded there also.

In order to prevent waste of time by carrying calculations to an unnecessary degree of refinement, and so as to conform to established conceptions of fitness and proportion, the instructions given in Table 58*a* have been prepared for the use of the author's assistant engineers.

TABLE 58*a*

ACCURACY OF CALCULATIONS

In all calculations figures are to be given to the nearest unit noted in the following table:

1. Effective span	0.1 ft.
2. Effective depth	0.05 ft. or 0.5 in.
3. Height to lift	1.0 ft.
4. Loads	
a. Per square foot	1 lb.
b. Per lineal foot	10 lbs.
c. Concentrated	100 lbs.
d. Load to lift	1000 lbs.
5. Shears	1000 lbs.
6. Stresses	1000 lbs.
7. Moments.	
a. Stringers, floor-beams, etc.	100 ft. lbs. or 1000 in. lbs.
b. Main girders	1000 ft. lbs.
8. Live-load impact	0.5%
9. Ratio $l \div r$	1 unit
10. Unit stresses	10 lbs.

Next the weight of metal in the trusses is estimated. For ordinary spans, the weights of details are taken from Figs. 55*f* and 55*w*; but if the structure be of an unusual type or size, the details are sketched and their weights are computed.

Next the total weight of metal in the structure is figured, and the dead load is checked. If it does not agree with that assumed within the limit of error set in the specifications, a new dead load is assumed, and the entire computations of total stresses, sections, and truss weights are made anew. It is very seldom, however, that it is necessary to make these calculations more than once, owing to the great mass of accumulated data concerning weights of metal in all kinds of bridges, as recorded in Chapter LV.

The exact lengths of all members, including camber allowances, are then figured and recorded on the last-mentioned diagram, preferably in blue ink.

In determining stresses graphically, the frame diagram should be laid out on as large a scale as is convenient, and the load diagram should be made as small as practicable; for the large frame gives great accuracy in inclinations of members, which is the all-important point in graphical computations, and the small load-diagram confines the graphics to a reasonable space. If the inclinations are correct, accurate results will be

obtained with a very small load-diagram. The author's limits of error for graphical work are one-quarter of one per cent at mid-span and one per cent at the far end of span. Should the error exceed these limits, the graphical work has to be done anew. Smooth paper, sharp pencils, true triangles, and perfect straight edges are necessary to secure good results, to which list should be added painstaking accuracy in every manipulation of the appliances.

The calculations for girder spans and for steel trestles and viaducts are made in a similar manner to that just described for truss spans, except that in trestles and viaducts attention has to be paid to the combinations of stresses in towers, as explained in Chapters XIII and LXXVIII.

In respect to the calculations for reinforced concrete arches, that subject has been very thoroughly treated in Chapter XXXVII. consequently nothing further on the subject need be said here.

In regard to the calculations for reinforced concrete girder spans and trestles, the sequence of designing is as follows: Floor slabs, stringers, cross-girders, main girders, columns or piers, and footings. The method of figuring each of these items is very thoroughly explained in Chapter XXXVII, hence there is no necessity for making here any further comment thereon.

Checking Calculations

In making any set of calculations the computer should check back on his work at short intervals, so as to see that no error has been made, because the effects of such errors often extend over all succeeding computations.

All calculations on the standard sheets, except as previously indicated, are made in black ink; and when they are checked by another computer, as is the invariable custom in the author's office, all check-marks and corrections are made in red ink, and each page checked is so marked and initialed by the checking computer, who not only verifies all the numerical calculations, but also follows carefully each step in the design so as to guard against all possible errors. The work of checking is greatly facilitated if all the steps taken are indicated plainly, so that they can be easily followed by the checker. Each result checked is ticked off with red ink.

Making Drawings

Owing to the necessity for having several copies made of each drawing, the latter is first laid out in pencil on detail paper, and is copied in ink on tracing cloth. In some simple designs, however, the penciling is done directly on the tracing-cloth, but this is the exception rather than the rule. For convenience in handling and filing, it is very desirable to have all drawings made of a uniform size. After several years of experi-

ence, a size of twenty-nine inches in width and thirty-eight inches in length has been adopted as best suited for bridge plans. This size may be used for all detail drawings and stress-diagrams, but it is often necessary to increase the length for profiles and general drawings. The drawing is always made on the rough side of the tracing-cloth, as it is often convenient to do a considerable amount of drawing and writing in pencil on the sheet. Another reason for using the rough side is that any erasure shows less thereon than it would on the smooth side, and it is often necessary to do considerable erasing on tracings. As before stated, the first drawings to be made are the general profile and plan, with cross-sections, in order to establish all the main dimensions of the structure. These drawings can be prepared before the computations are finished. Next come the stress-diagrams, which should contain for steel structures the cambered lengths of all members; the dead load, live load, impact, and wind-load stresses, and the greatest combinations of same; the sections required and those used for each main member; and the following general data:

1. Length of span from centre to centre of end-pins.
2. Number and length of panels.
3. Perpendicular distance between central planes of trusses.
4. Depths of trusses.
5. Dead load for floor system per lineal foot of span
6. Dead load for trusses per lineal foot of span.
7. Live load for stringers per lineal foot of span.
8. Live load for floor-beams per lineal foot of span.
9. Live load for trusses per lineal foot of span.
10. Wind load on upper lateral system per lineal foot of span.
11. Wind load on lower lateral system per lineal foot of span.
12. Clearance required above base of rail or floor.
13. Specifications.
14. Kinds of materials to be employed in all parts of structure.
15. Diameters of rivets to be used.

The stress-diagram proper may be simply a line-drawing, each main member being represented by a single right line, or all the main members may be drawn to scale by means of their periphery-lines. The latter method is generally adopted because of the improved appearance of the sheet which it affords. The scale for any stress-diagram should be large enough to give plenty of room between panel points to contain all the necessary writing.

After the stress-diagrams are completed, the detail drawings are begun. There is considerable difference in the methods employed by consulting engineers to convey to manufacturers an understanding of the design which they desire to have executed in the shops. Some insist that the only proper method for the engineer to pursue, if he desires his details

to be followed, is to make complete working or shop drawings, ready to be turned over to the template makers; while others prefer to make what are termed general detail drawings, which show to exact scale all the details, and give all important dimensions and the number of rivets in each connection, but which do not locate each rivet by figures, leaving the working drawings to be made by the manufacturer. When the latter method is adopted, the working drawings must be sent in duplicate to the engineer for his approval before any of the work is sent into the shops, the said drawings being checked by the engineer's assistants, not only to see that they agree in every important particular with the original drawings, but also to make sure that they contain no errors of any kind. The latter method is the one which the author invariably employs, and for adopting it he gives the following reasons:

First. Each bridge-shop has certain methods of doing work, which demand that the working drawings be made in accordance therewith; otherwise the cost of the manufacture is materially increased. These methods cannot be considered by the engineer, who has neither the time nor the inclination to go to the trouble of acquainting himself with the various methods of all the leading bridge-shops of the country.

Second. The nature of the work of a consulting engineer is not such as to justify him in keeping together enough trained draftsmen to execute with sufficient rapidity the large amount of drawing necessary, if the first-named method be followed.

Third. The capacity for accomplishing work in a consulting-engineer's office when the second method is employed is probably three times as great as it would be were the first method adopted.

Fourth. With the careful and thorough system of checking shop-drawings in vogue in the author's office, all the advantages to be gained by making complete working drawings are obtained by the much simpler method of making complete detail drawings.

Fifth. The manufacturer always appears to be better pleased and satisfied if the making of the shop-drawings be left to him; and the work of manufacturing the metal proceeds more smoothly in consequence.

In starting a detail drawing, the first thing to be done is to lay out a sheet of standard size. If the subject be a framed structure, such as a bridge or roof truss, it will greatly economize space on the drawing if the skeleton frame be laid out on a small scale, say three-eighths or one-half inch to the foot, thus giving the proper inclinations of all members, and if the details at all the panel points and connections be made to a larger scale, say three-quarters of an inch or an inch to the foot. The centre-of-gravity lines of all main members should coincide with the lines of the skeleton diagram. For the details of ordinary bridges the scales just mentioned will be found the most satisfactory. It is a very common error among bridge-draftsmen, when two different scales are used, to make the principal lines of the main members continuous be-

tween panel points, thus exaggerating the apparent size of the said members. This is entirely wrong, and is often the source of serious errors in the shops. In such drawings, the main members should be broken off before their principal lines meet midway between the panel points; and it is often advisable to show a section of the member between the broken ends.

After deciding upon the scales, the next step is to determine what portions of the structure are to be shown on each sheet, if more than one is to be made, and what is the best possible arrangement for all details on each sheet so as to fill it uniformly and allow ample space for illustrating each detail in the requisite number of views. For short spans, up to, say, two hundred feet, by carefully arranging the details, everything can be shown clearly on a standard sheet of twenty-nine inches by thirty-eight inches. The sizes of all connecting-plates, stay-plates, lacing-bars, connecting-angles, pins, fillers, rivets, etc., should be given, also those of all main members; and the exact spacing from back to back of all angles, channels, and webs forming the various members should be clearly indicated. The packing at all panel points should be shown, and the exact spacings therefor should be given by figures. There should be indicated also all leading dimensions, such as the exact cambered lengths from centre to centre-line of pin-holes for all truss members; the vertical distance from centre of bottom-chord pins to base of rail; the vertical distance from centre of bottom-chord pins to bottom of floor-beams; the vertical distance from base of rail to top of masonry; the clearance required above base of rail; the spacing of anchor-bolts; the lengths of all built members beyond centres of pin-holes; the spacing of rivets in flanges of stringers, floor-beams, and chord members in a general way, such as "16 spaces of 3″ each," or "about 3″ spacing"; the distance from back to back of opposite flange angles in all girders and struts; the widths of webs of all plate girders; the spacing of stiffening angles; etc., etc. All joints or surfaces which are to be planed or faced should be so indicated.

Each sheet should have a general and descriptive title printed in a neat but plain style of lettering. The title and the number of the drawing should be placed in the lower right-hand corner. This work can best be done by setting type and employing a hand-press. A single line drawn one-half inch from each edge of the sheet should define its margin, and if a rather fine line be drawn for each boundary of the tracing, and the sheet be trimmed just up to these boundary-lines, the blue-printer will have a well-defined border to which to cut his prints. All lettering should be plain, but executed in a neat and workmanlike manner. Nothing adds more to the appearance of a drawing than neat lettering. Special care should be taken to locate all dimension-lines so there can be no doubt as to the distances they are intended to fix. All notes should be written in positions where they will be easily noticed, and so that they will not

interfere with the lines of the drawing. A set of general notes should be given on each sheet of details, specifying the kinds of material, the sizes of rivets, the diameters of rivet-holes before and after reaming, the manner in which all plates are to be finished, etc. After each sheet is penciled, it should be checked carefully to see that there are no errors thereon; then, after the tracing is finished, it must be checked in detail—if possible by some one who was not concerned in its preparation. The checking, as a rule, must not be done on the tracing but on a blue print made therefrom. This prevents the tracing from being injured by handling, marking, and erasing. It also enables the checker to tell more certainly when all corrections have been made, and gives a permanent record of all changes. These prints should be plainly stamped or marked "Checking Prints." They can be destroyed as soon as it is thought advisable to do so.

As indicated at the outset, the preceding notes apply essentially to steel bridges and trestles; but in general they will serve also in relation to reinforced concrete structures. All dimensions of the concrete must be clearly shown, and the sizes and arrangement of all reinforcing bars must be properly indicated. It will frequently be advisable to make one drawing showing concrete details only, and another one for the reinforcement. A scale of one-quarter or three-eighths of an inch to the foot will usually be found satisfactory; but for complicated details, such as those at expansion joints, it will often be best to adopt a larger scale. The general notes on each sheet should cover such points as the permissible edge distance and spacing of bars, the amount of lap required at splices, the minimum radius of bend allowed for bars under stress, and the dimensions of hooks on the ends of bars. The locations of construction joints should be indicated on the drawing, or else should be covered by the general notes.

Checking Drawings

The following standard instructions of the author to his office-assistants concerning the checking of drawings will indicate what such checking should accomplish and the essential thoroughness thereof.

General Detail Drawings

First. Go over all drawings for the entire design and see that every detail of the structure is shown in a sufficient number of views to make clear to the manufacturers exactly what is intended by the designer.

Second. See that every detail has been dimensioned so that it can be readily laid out on the working drawings. See also that all sections of connection angles, fillers, etc., are indicated.

Third. See that proper descriptive notes are given wherever necessary to make clear the reasons for any special details.

Fourth. Examine each detail and see that every portion of it is strong enough to carry properly the greatest stress that could ever come upon it were the greatest possible capacity of the main member or members utilized. Make sure that enough rivets have been used, and that they are indicated to be countersunk or flattened wherever necessary to provide proper clearance.

Fifth. In checking up the packing at the panel points, see that all members which are to be brought on to the pin are shown, and that a sufficient clearance has been figured for each. Make sure that all forked ends have the requisite strength, and that diaphragms between the same have been used wherever necessary. Check up the bearing of each member on the pin, and make sure that plenty of rivets have been employed to convey the stress from the extension-plates to the main member. Remember that the stress to be provided for at the bottom of a vertical post is not the stress on the post itself, but the algebraic sum of the vertical components of the stresses in all diagonals attaching to the pin at the foot of post, or, approximately and on the side of safety, the stress on the post plus one-half of a panel floor-load. See that no bar diverges from the central plane of truss more than one-eighth ($\frac{1}{8}$) of an inch to the foot. See that fillers are shown and their sizes given wherever they are necessary to hold the members to exact position on the pins. Check all pins for the greatest bending moments coming on them, determining the same by combining the bending moments in two directions at right angles to each other.

Sixth. See that the centre-of-gravity lines of all members are shown; and where any such line is not in the central plane of member, see that it is located from the side of the section.

Seventh. Wherever a drawing is either wholly or partially shown in section, see that the exact point at which the section is taken is indicated in writing, and that the section line is properly indicated on the other views to which the note refers.

Eighth. Compare all sections of members and all leading dimensions with those given in the calculations, and see that they correspond thereto.

Ninth. See that all stay-plates and lacing-bars are shown, and that the sizes for same are given; also that these sizes comply with the requirements of the specifications. The inclinations of all lacing-bars should be given.

Tenth. See that all extension-plates of forked ends are carried at least six inches inside the end stay-plates, and that they are strong enough to develop the full strength of the main member, even though the computed stress thereon be small.

Eleventh. Check all forked ends for transverse bending, and see that they have been reinforced wherever necessary.

Twelfth. See that all reinforcing-plates at ends of members are so distributed as to balance as nearly as practicable the bearing on the two sides of the main section.

Thirteenth. Compare drawings which show the same details, so as to make sure that all are alike.

Fourteenth. See that the same style of detailing has been followed on all drawings. Where several draftsmen are employed on the same piece of work, there is liable to be quite a diversity of details, illustrating the individualities of the various draftsmen making them.

Fifteenth. When a change is made in any part of a drawing, see that the said change is carried through all the sheets which are affected thereby.

Sixteenth. See that when any drawing or portion thereof is abandoned it is so indicated clearly throughout all the drawings.

Seventeenth. Wherever timber-bolts are to be used, see that they are plainly indicated, that their sizes and lengths are given, and that washers are provided beneath all heads where the bearing is on the wood.

Eighteenth. See that all screw-ends of rods are upset, unless they are to have cold-pressed threads. See that all diagonal rods are provided with proper adjustments, and that all clevis-pins and plates are of proper strength. See that no pins of less diameter than allowed in the specifications are used, and that they are set at least one and one-half diameters from edge of plate.

Nineteenth. In reinforced concrete structures, see that all dimensions of the concrete are clearly shown, that the number and the arrangement of all reinforcing bars are properly indicated, that the locations of construction joints are specified, and that at no point have unduly thin sections been used.

Twentieth. See that each sheet is provided with general notes as follows:

Steel Structures.

A. Kinds of material to be used throughout the structure.
B. Diameters for rivets.
C. Sizes of rivet-holes before and after reaming.
D. Manner in which the edges of all web-plates are to be finished.
E. What ends are to be faced and what are not.

Reinforced Concrete Structures.

F. Permissible edge distances and spacing of bars.
G. Amount of lap of bars at splices.
H. Minimum radius of bend allowed for bars subject to stress.
I. Dimensions of hooks on ends of bars.

Twenty-first. See that all notes are written in good English, that all words are spelled correctly, and that they express exactly what is intended.

Twenty-second. See that each drawing is provided with proper titles, that it is numbered correctly, that the scale or scales are indicated, and that the name of the draftsman and date of completion of drawing are given.

Twenty-third. See that the drawings scale, and, if they do not, make

a note saying that the dimensions written on the drawings are to be followed in preference to the scale where there is any discrepancy between the two.

Twenty-fourth. In short, check over all details, dimensions, sections, and notes given on the drawings, so as to make sure that everything is in strict accordance with the specifications and with the data furnished for the structure.

Shop Drawings.

First. Make sure that the sections and details conform in every particular with those given on the general detail drawings and stress-diagrams, excepting in minor points, where slight changes may be made to facilitate the work in the shops, provided, of course, that such alterations do not in any way impair the strength, durability, or appearance.

Second. Check over all field connections to see that there are no rivets which are so located that they cannot be satisfactorily driven in the field.

Third. See that all members have proper clearances at panel-points, and that all rivet-heads, wherever necessary to provide such clearances, are countersunk or flattened.

Fourth. Check over all lengths of members and rivet-spacing for field connections to make sure that the holes will match in the field.

Fifth. Check over all bills of material to see that the correct numbers of pieces have been ordered, and that they are of proper sections and lengths.

Sixth. Always have the shop-drawings sent to the office in duplicate and check the two sets, retaining one set in the office and returning the other set with corrections or approval marked thereon. Where drawings are returned to shops with corrections marked on them, revised prints must be sent for approval before the work is put into the shops.

Changes on Tracings

It is often necessary to make changes on a tracing, and in doing so great care should be exercised, otherwise a drawing which has cost considerable time and money may be ruined. For making slight erasures a very soft pencil-eraser is best, and next comes the rubber ink-eraser, but sometimes a very sharp knife skilfully used will be found effective, as it can be so manipulated as to affect nothing but the parts to be erased. The latter should be employed only with extreme care. Where only a slight erasure is to be made, an erasing shield—a thin sheet of metal in which are cut small holes corresponding to the work to be changed—should be used. This sheet is laid on the drawing so that a hole comes over the part to be erased, then an eraser is rubbed over the hole, and nothing is damaged except the portion which is changed.

Filing Drawings, Calculations, Specifications, etc.

In the course of a few years' practice the office records of a consulting engineer grow to such proportions that, unless some systematic method of filing and indexing them be adopted, it is impossible to refer thereto without a great deal of delay and annoyance. The filing of calculations and specifications is a comparatively easy matter, but to keep an accumulating lot of drawings in good shape for ready reference is by no means such. During the time that the author has been engaged in active practice several methods have been employed for filing tracings. One great difficulty with the earlier drawings was that they were of varying dimensions, some as large as forty-two inches by ninety-six inches, and others belonging to the same set as small as eighteen inches square. At first large cases of drawers were used for laying out the tracings flat, each tracing being stamped with numbers designating the lot and drawer to which it belonged, and an index being kept of all drawings, recording the numbers of the lot and drawer. The objections to this method were that the smaller drawings got lost among the larger ones, thus often necessitating a complete overhauling of an entire drawer to find a tracing, and it was impossible to keep the large drawings from becoming folded and cracked at the edges and corners. Later it was deemed advisable to bind each set of drawings together with patent fasteners along one end, but this method was soon abandoned, owing to the difficulty encountered in getting out tracings for blue-printing and reference.

The method of laying the tracings flat in drawers was abandoned for a while, and that of filing them in cardboard tubes with tightly fitting covers was tried. This served the purpose fairly well, but it had its defects, hence it, in turn, was abandoned for the one now in use, which is as follows:

The tracings are filed in flat drawers in heavy paper envelopes containing about ten tracings each, there being some ten or twelve envelopes to a drawer. There is a special file for record drawings, and there is another for finally approved shop-drawings. There is also a file for calculations; and all periodicals that are not bound permanently, all important catalogues, all specifications, and all other materials that may prove of use in the future are filed methodically. All files are thoroughly indexed so that anything wanted can be found very quickly.

The specifications and calculations are kept in filing cases prepared especially for them. These cases consist of a series of small shelves about one and a half inches apart, each shelf being numbered. When a set of calculations is complete, the sheets are all bound together in one book with removable fastenings, so that they can be easily separated when it is necessary to distribute them among several draftsmen. These sets are all numbered with the numbers of the shelves on which they are to be filed.

In indexing all work, every article should be registered under as many headings as practicable.

General

All calculation-blanks should be of an extra-good quality of paper, capable of withstanding a great deal of erasing and scratching, which is often necessary in making sketches for details. The tracing-cloth should be of the best quality, as it is impracticable to make a good drawing on poor cloth. The best brand that the author has ever used is the Imperial.

Pounce or talcum should be rubbed over the surface of the tracing-cloth to make it take the ink uniformly. Pencil-marks and dirt can be easily removed from a tracing by moistening a towel in benzine and washing the surface of the cloth with it. If a good quality of ink be used, it will not be affected by such washing.

There are many liquid India inks in the market, but none of them will give quite as good results as will the genuine stick ink when properly ground; nevertheless, except for very fine work, the former are preferable on account of the saving of time which they effect. Higgins's waterproof ink is the most satisfactory which has yet been tried in the author's office.

A good quality of detail paper is very essential, for there is in all kinds of detailing a great deal of erasing to be done; and time is always saved by using good, tough paper that does not rough up by having an eraser used upon it.

Handling Office Work

There will now be given a complete description of the manner of handling the office work as developed by the author's firm; and while this is really the result of the evolution of a practice extending over nearly three decades, as far as the drafting department is concerned it is mainly the work of Herman H. Fox, Esq., C. E., who for many years and until about the end of 1914 was Chief Draftsman for the firm, and who since then has been aiding the author in the accumulation of data for this treatise. Throughout this description, however, it must be remembered that the various details have been evolved for an exceedingly large practice, and that they do not necessarily apply to an office where such a practice does not exist. A modification of the system may be advisable for any particular case, or possibly it may not be applicable at all for any office besides that of a consulting bridge engineer.

The work of the firm was carried on in what might properly be termed three separate departments, consisting of the General Office or Business Department, the Designing Department, and the Drafting Department. While these divisions were distinct in so far as each occupied quarters devoted entirely to its own particular work and was in charge of a single

head responsible only to the Office Manager, there was a common interest in the office as a whole which necessitated a close relationship between the various branches in order to carry on the work systematically and economically. The members of the firm had their own private offices; and while in the office they were in daily touch with all of the departments giving directions and suggestions where needed.

The General Office was in charge of a secretary or chief-clerk, under whom worked a bookkeeper, a stenographer, and an office boy. All correspondence, drawings, prints, and data of every description passed through this department, whether they were coming into or going out of the office. The secretary opened all correspondence and referred it to the persons concerned. All letters containing information regarding the work in the Designing or Drafting Departments were copied; and the copies were sent to the heads of these, as originals were not permitted to be taken out of the General Office, except in very urgent cases when it was not considered advisable to wait for the copy to be made. These copies were stamped, "For Attention of Mr. ———" or "For Information of Mr. — —." In the former case the recipient of the copy was expected to follow up the correspondence and answer it; whereas, in the latter case, he was expected to use the information given and file the copy for reference, nothing further than this being necessary.

The originals were always stamped the same as the copies; and all letters were stamped with the date and hour when received and when copied. If the copies were not sent out immediately, the recipient usually noted the fact thereon, adding the date and hour when they reached his hands. The original of all letters of interest to either member of the firm were referred to him directly. Where the "attention" note appeared, he either asked the recipient of the copy to refer the matter to him before framing the answer (if he was particularly interested in it), or laid the letter aside until the answer was placed on his desk. All letters by the heads of the departments generally passed through the hands of the Office Manager and were sent by him to the General Office for mailing. All original letters received were filed by the General Office, the copies being kept in the files of the department heads. Copies of all correspondence by the various men in charge were filed both in their own files and in the General Office. No one, except the heads of the departments, was allowed in the General Office, unless on special business. Prints, drawings, and other data were handled in the same way as the correspondence; except that after being stamped as to date and hour received, they were passed out directly to the proper department.

The stenographic work for the entire office was handled by the one stenographer, who was assisted occasionally by help from outside, when there was a great rush of copying to be done. By means of a buzzer system she was notified when wanted.

The Office Boy attended to all of the filing in the General Office and

saw that all letters, prints, data, etc. were delivered promptly to the right persons. He looked after the mailing, and went on all necessary errands. He also performed other services of a general nature around the office.

All purchases whatsoever were arranged for by the General Office. Requisitions were made out by the department heads—mostly by the Chief Draftsman—and these were turned in to the Chief Clerk, who O. K.'d them and ordered the materials. All payments were made through the General Office over the signature of a member of the firm, or, in the absence of both, over that of one of the two principal assistant engineers. This was true both as to purchases and salaries. All cost-keeping and accounts were likewise looked after by that department.

All work was handled separately under job numbers, which were assigned by the Chief Clerk. No distinction was made between proposed and final jobs in this connection, although in every other way these two main divisions were kept separate.

The Designing Department consisted of the Chief Designer with such assistants as were required at different times. As a rule, the Chief Designer made all calculations himself both for preliminary estimates on proposed work and for the final construction. When unable to turn these out in the allotted time, he secured from the Drafting Department such help as was needed to complete the work. He likewise obtained assistance from that department for checking the calculations or for preparing such drawings as came under his supervision. These consisted of the General Layouts, Stress Sheets, and any other drawings affecting the design directly. The checking of erection schemes, sent in by the contractors for approval, and the assimilation of other data of a nature that affected the design were handled by this department. When men were turned over to him to take care of such work, they were entirely responsible to him until he released them. The Chief Draftsman was always advised when these men completed their work in the Designing Department; in fact the approximate time of such completion was given him beforehand, so that he could have work ready for them on their return to the Drafting Department.

The calculations were drawn up on the special form shown in Fig. 58*a*. A white translucent paper was used so that prints could be made. The sheets were ruled with blue lines in one-quarter-inch squares, every tenth line in each direction being red. A title form appeared at the top of each sheet. At the beginning of any set of calculations, a data sheet, as shown in Fig. 58*b*, was first filled out. A yellow color was used for this so as to make it stand out conspicuously from the rest of the calculations. As seen from the sketch, this sheet gave the complete notes covering the principal features of the structure, and indicated what specifications governed the design. The calculations were generally worked out in logical sequence, beginning with the floor and following with the stringers, floor-beams, lateral bracing, vertical sway bracing, portal brac-

ing, and trusses or girders. These were followed by special calculations, such as those for counterweights, towers, machinery, etc. The sequence naturally was arranged to suit the particular type of structure being designed. This remark refers especially to the superstructure. In the substructure no such condition exists. The substructure calculations were made either first or last, depending on the demands for getting out the plans for it. Where a separate contract was let for the substructure prior to the letting of the superstructure, the former course was necessary. From the weight curves in the office the superimposed loads were readily figured and the design made. When the superstructure calculations were completed these loads were checked by the actual loads.

For proposed jobs and small constructions the calculations were worked up in a single section. However, on large jobs it was found advisable to break up any one set of calculations into numerous sections for ease in handling and convenience in getting out the work. These sections were arranged to accord with natural divisions in the structure, such as substructure, truss spans, plate-girder spans, trestle approaches, counterweights, towers, machinery, etc., and they were lettered A, B, C, etc. A title sheet, drawn out on the regular calculation paper and giving the name of the bridge and the letter and title of each division, was bound in with it at the front. As these divisions were checked, they were turned over to the Chief Draftsman for the preparation of the drawings. They were filed, as explained later, after the detail drawings were completed. After the calculations were once checked, no notes of any kind (either in pencil or in ink) were permitted to be made on them. Whenever revisions were considered advisable, they were first brought to the attention of the Chief Designer. At a convenient time he looked into them and had them attended to. Every revision made was properly marked, and the mark was given at the top of the sheet, together with the initials of the maker and those of the checker, as well as the dates on which the revision was made and checked. On the white title sheet the numbers of the sheets revised, the fact that they were revised, the initials of the maker and checker, and the dates of marking and checking of the revisions were given. These changes were kept track of by revision blanks shown in Fig. 58c. Whenever a part of the calculations was replaced completely by a later design, all sheets affected were marked "VOID" in large plain letters so as to preclude any chance of their being used. The person who marked a sheet "void" noted thereon his initials, and the date; and a reference to the sheet replacing it was noted when advisable.

After the calculations for the whole job or any section of it were completed, the preparation of the drawings was begun. This procedure was not always followed, as it was sometimes necessary to start the drawings before the calculations were checked. In this case, the Chief Designer had blue prints made for the use of the drafting room. At times this entailed extra work when changes were made in checking; however, modi-

fications of any importance rarely occurred. As was stated before, the General Layout and the Stress Sheets were usually prepared under the supervision of the Chief Designer; all other drawings, however, were made in the Drafting Department. This department was in charge of the Chief Draftsman, who had from ten to thirty-five draftsmen under his control, depending on the amount of work under way at any one time. A Drafting Room Clerk and a Blue-printer completed the force. During slack seasons extending over any length of time, the Blue-printer was dispensed with and his work was taken care of by the clerk. The preparation of detail drawings, the making of blue prints, the checking

REVISIONS

CALCULATIONS............................

DRAWINGS...............................

JOB NO.............. SHEET NO.............

WORK	NAME	DATE	REMARKS
Made by			
Checked by			
Corrected by			

FIG. 58c. Revision Blank.

of shop-drawings, the handling of the department's special correspondence, and the care of records, files, indices, etc., pertaining to the work of the Designing and Drafting Departments, were all looked after in this department.

The work was handled by squads consisting of a Squad-boss and from four to six draftsmen under his direct supervision. With ten or less men in the drafting room the Chief Draftsman directed all of the work personally; but when he had special matters to look after himself, he appointed an assistant to take charge of the men for him. It was always attempted to give the Squad-boss enough men to keep him busy directing their work and settling such questions as might arise, in addition to the general planning of the work and the laying out of important details. Moreover, questions brought up outside of the office, particularly with reference to his own work, were, as a rule, referred to him. At times he was given special investigations to make; and these were reported upon to the head of the department. Certain correspondence was likewise

turned over to him. The draftsmen were responsible to the Squad-boss alone, who assigned them their work; and at no time were they given instructions by anyone else. When the Chief Draftsman, in his daily rounds, noted changes that should be made, he always called in the Squad-boss on the discussion and then left him to give final instructions. In the same way any member of the firm, desiring changes of any importance, called these to the attention of the Chief Draftsman, who attended to their being carried out properly. In all cases it was aimed to maintain the authority and prestige of any individual who occupied an executive position.

The Squad-boss laid out the work for each man under him and watched it throughout its progress. He arranged this so that it would be unnecessary for the various men to discuss the details among themselves, as it was intended that each man should carry on his work alone, referring such matters as required the Squad-boss's attention directly to him. Generally, the Squad-boss settled all important points early in the job and instructed the men as to his decisions regarding them. These were usually in the nature of general details or specifications covering the work of more than one man or of special details requiring particular ingenuity in their solution. At all times it was attempted to limit technical discussions to the Squad-boss and each individual under him, as discussions between the men themselves were found to be long-drawn-out and to lead to nowhere. For the same reason communication between men in different squads was limited as much as possible. Hard-and-fast rules were not adopted in this regard, as it was not intended to curtail absolutely the freedom of the men. It was considered advisable, however, to determine the sources of authority and have these resorted to when necessary. Care was always exercised to handle the work economically and with the least red-tape possible and yet to fix the responsibility of each individual. Moreover, it was practically a necessity to have a quiet, yet busy, working force; and promiscuous discussions did not contribute to this end. Ordinarily, only the checking of detail drawings prepared in the office was handled independently of the Squad-boss. The checker was held responsible to no one except the Chief Draftsman, in order to prevent his being influenced by any one connected with the work. He was at liberty to discuss any detail with the Squad-boss or detailer, but was free to use his own judgment after such a discussion. Only the Chief Draftsman could settle a difference of opinion between the two as to the best detail to employ. Occasions sometimes arose when it was advantageous to handle certain special investigations outside of the squad; and the men carrying on such work were placed under the direct supervision of the Chief Draftsman.

The squads were not permanent in their organization, as it was necessary to arrange them to suit the existing conditions at any particular time. Moreover, it was the purpose of the office to give each man as

rounded an experience as possible, because this course resulted in benefit to the office as well as to the individual. Naturally, the individual had to be equal to the responsibilities placed upon him or he would not have been entrusted with them. With this system in vogue, different men were in charge of different squads at different times; and the men in the squads were shifted from one to the other as circumstances demanded. As a rule, the abler and more experienced men were made Squad-bosses; although sometimes younger men were placed in charge, particularly when they showed themselves specially fitted to handle men. Likewise the older men were placed in charge of checking work, on account of their experience. Generally, the least experienced men were put on the tracing and the correcting of drawings, while the more advanced ones devoted themselves to detailing; but sometimes it was necessary for the latter also to make tracings. The work was arranged so that a single squad either handled the entire job or took care of one or more divisions of it. The former arrangement was possible on small jobs; but on large ones where the layout was considerably varied, it was necessary to follow the latter course. In this case the divisions were made as complete in themselves as it was practicable to make them in order to avoid the overlapping of details and, consequently, also a division of responsibility between the various squads engaged.

When the calculations on any piece of work were turned over to the Chief Draftsman, he studied them carefully and determined what drawings were necessary and along what lines they were to be worked up. A complete list of drawings was made out at the start so as to obtain a consecutively arranged set of plans. Care was taken to see that there were enough drawings to cover all the details without the necessity of crowding any sheet. This usually called for considerable study, but it was well worth while; for, in addition to producing a logical set of drawings, it gave a working skeleton for the entire job and permitted the making of an accurate estimate of the time and number of men required to turn it out. The Chief Draftsman then arranged for a squad to prepare the plans, and turned over the calculations to the Squad-boss, giving him written instructions as to the handling of the work. The Squad-boss reviewed these thoroughly and then laid out the work for each man under him. He decided upon such details as lacing bars, stay plates, kinds of splices to be used, etc., so as to make the practice uniform; and he determined the amount of detailing necessary so as to avoid any duplication. Special instructions and notes were written so as to prevent any misunderstanding or any excuse for neglect on the part of the men. General decisions of importance were always written and placed on file, and copies were furnished the draftsmen for reference. Small letter-size sheets, $8\frac{1}{2}'' \times 11''$, were generally blocked out, giving the details to be worked up and their location on the drawing. These were turned over to the draftsmen, together with the calculations. The Squad-boss also

investigated important details that required special attention, drawing them out as far as it was necessary in order to determine the governing features, and then turning them over to the draftsmen to be completed and incorporated in their work. It was always attempted to have these ready for the men before they got to them. In such work as the detailing of trusses, the Squad-boss invariably studied the entire make-up of all the members, with the object of securing the best arrangement for splicing and for fixing the relations between the web and the chord members. It was frequently necessary to revise slightly the sections given in the calculations in order to secure the desired result, especially on heavy work. Such revisions, as well as others made by the draftsmen themselves, always followed the course previously outlined. To assist in turning out the drawings quickly, as well as to standardize the office practice, typical details and methods of designing them were worked up, and prints thereof were given to the draftsmen for use in detailing. In a few cases it was possible to prepare standards; but, as a rule, the work in the office was so varied that this was not feasible to any great extent. These typical and standard details were drawn out on letter-size sheets, $8\frac{1}{2}'' \times 11''$. A sheet for standard lettering, linework, and conventional signs was likewise prepared for the use of the draftsmen.

Almost all detailing was done on paper in pencil and then copied on tracing cloth in ink. Certain work was sometimes pencilled directly on the tracing cloth and then inked in; but this was the exception rather than the rule. In the preparation of the pencil drawing, care was generally taken to see that it was made exactly as it was expected to be traced. This was not always the case, however, as it was not infrequently found advantageous to detail on small sheets and adjust these on the drawing in tracing them. This system was found convenient in working up a drawing the entire detailing of which could not be done at one time, either for lack of information or on account of the necessity of waiting on some other detail not yet determined. Care was always taken to see that the pencil work was carefully done, so as to give no trouble in making the tracing. If it became necessary to lift the cloth in tracing in order to make out any detail or lettering, it was called to the attention of the detailer so as to prevent a similar occurrence on future work. Particular attention was given to the line work, especially in regard to its weight and make-up, as the conventions adopted by the office had to be adhered to. A pencil sufficiently soft to give a clear, distinct line and yet hard enough to prevent smudging was used. Certain important lines, such as centre lines, bounding lines, etc., were frequently inked in on the paper, especially on heavy work where considerable erasing might naturally be expected. The location and composition of titles, notes, and the like were also carefully watched on the pencil drawings, although the style of lettering was not considered material so long as it was distinct and legible. After the drawings were traced, the titles, which were outlined by the

Squad-boss, were printed on the sheets in the lower right-hand corner. The titles were arranged so as to occupy a space about six inches long and four inches wide. A small hand press was used for printing the titles; and they were set up and stamped by the clerk.

After the tracings were completed, the drawings were checked. Prints were made for this purpose in order to save the tracings. All corrections were put on the prints in ink, and the approved details were properly checked. The checker generally completed a whole sheet before taking up any questionable points with the detailer or Squad-boss. This avoided an unnecessary amount of running back and forth as well as the constant interruption of the various men concerned. Of course, this practice was not always adhered to, as it sometimes happened that such matters involved the further checking of the work. In such cases the points in question were invariably settled as they arose.

After the drawing was completely checked, it was returned to the Squad-boss, who turned it over to the detailer for back checking. The latter checked the corrections and, when through, took up with the checker such changes as he did not agree to. These differences were then settled between the two; but when no agreement could be reached, the point in question was referred to the Squad-boss and, if necessary, to the Chief Draftsman for settlement. After this, the tracing was corrected in accordance with the checking print and returned to the checker. He then ticked off every detail on the tracing, comparing it carefully with the checking print. Where proper changes had not been made, these were noted on the tracing, which was returned for further correction. Finally, after it was approved, it was signed by all parties connected with it where indicated on the title. The checking prints likewise were signed by all parties concerned, and the dates on which the checking, back-checking, and correcting were done were added. The checking prints and the pencil drawings were filed away until the shop drawings had been approved, after which they were destroyed. This was done merely for reference in case the shops should find errors in the drawings. As far as it was possible to do so, one man was given the checking of an entire job or a definite section of it, so as to fix the responsibility for the work. Where several checkers were put on one job, they were expected to compare overlapping details so as to be certain that no differences occurred on that account. The Squad-bosses likewise watched this particular point in connection with the detailing.

Calculations required in the detailing and checking of drawings were made in standard figuring books containing 150 sheets about $10'' \times 12''$ in size. These sheets were quadrille ruled in one-quarter-inch squares, which made them especially suitable for this particular work. Each investigation was given a proper title, and each day the date was put on the sheet just started. Each book was indexed for ready reference. These books were kept by the draftsmen at their desks until they were

of no further use to them, when they were filed in a convenient place in the drafting room.

Although the standard sheet, 28″ × 37″ inside and 29″ × 38″ outside of the border, was mostly used for drawings, half-size sheets, 18″ × 28″ inside and 19″ × 29″ outside, were sometimes found convenient. Moreover, during the checking of the shop drawings and during the construction of the job, it was frequently necessary to send out a small sketch of a detail. For this purpose a letter-size sheet, 8½″ × 11″, was employed. The structural drawings were numbered 1, 2, 3, etc.; the mechanical drawings, M1, M2, M3, etc.; and the sketch sheets, D1, D2, D3, etc. Whenever a tracing was replaced by another, the original one was marked "VOID" in large letters near the title, with a note, "See final drawing No. ———." The new drawing took the same number as the original except that the letter A, B, or C, was added to it as a distinguishing mark to signify the number of times the drawing had been remade.

A concise record of the detail drawings was kept for each job on the form shown in Fig. 58*d*. The sheets were 10½″ × 16″, the same as those used for the calculations; and they were punched at the left hand end for a canvas-backed folder made specially for the calculation file. These records were placed in the folder in alphabetical order according to the title of the job, and were kept by the clerk. As soon as the list of drawings was made up, the above form was filled out to this extent. Then as the drawings were gotten under way, the record was extended until it was complete. The data for this were taken from the time-cards described later. The squares in the columns listed "Title," "Checking Print," "Back Checked," and "Corrected" were merely checked thus (√) when any of these items had been taken care of. By referring to this record one could see at a glance just where any particular job stood at any time.

After the tracings were checked, reference prints were made and turned over to the Squad-boss; after which the tracings were filed in the cabinets used for that purpose. These prints took the place of the tracings to a large extent, as otherwise the wear and tear on the latter would soon have put them in bad condition. They were used in the checking of shop drawings and in general reference work. Moreover, all important corrections, made after the drawings were first signed as being checked, were noted on these prints as a record of the same. These changes may have been due to the shops, to the owners, or to the office itself. These prints were kept until the job was completed in the field, after which they were destroyed. No pencil marks or notes of any description whatsoever were permitted on the tracings after they were checked. Where corrections were necessary, they had to be called to the attention of the Chief Draftsman, who saw that they were taken care of in the proper course.

The work of checking the shop drawings was turned over to the men

RECORD OF DETAIL DRAWINGS

Fo: .... Yea

Description of Drawing	SHEET NO.	File Number	DETAILING			TRACING			CHECKING			Title	Chkg Print	Back Chkd	Corrected	Signed	Remarks
			Name of Drafts'n	Date Begun	Date Comp't'd	Name of Drafts'n	Date Begun	Date Comp't'd	Name of Drafts'n	Date Begun	Date Comp't'd						

FIG. 58*d*. Drawing Record.

who made and checked the detail drawings, if they were available for this purpose. The shop prints were sent in in duplicate, one copy being for the office and the other for the shops. Only such items as the principal dimensions, sections, details, and strengths of all parts were checked. The rivet spacing was not looked into except to see that no spacing less than the minimum or greater than the maximum allowed by the specifications was used. Net sections were carefully watched for any improper reduction by the shops. The number of field rivets was checked in all cases; but the matching of field connections was not looked into. The shop lengths of all main members were checked, and the lengths of a few bracing diagonals were figured to see that the shops were giving them the proper draw. Items that affected the shops alone, but did not influence the strength of the structure, were not investigated. The checkers were instructed, however, to see that the details for the structure were complete and that the proper number of each was ordered by the shops. A point that often gave trouble in the checking of shop drawings was the fact that the shops frequently made corrections other than those noted by the checker without calling attention to them in any way. This was immaterial, of course, in unimportant details; but the fact that some important detail might be overlooked through this course led the Chief Draftsman to instruct the shops at the beginning of each job to underscore all such changes, no matter how unimportant they might be. This was found well worth while on more than one occasion. As far as possible, the corrections were made so fully on the shop drawings and in such a manner that the reasons for them would be evident to the shops. Where this could not be done, the correspondence was made to clear up the changes. The shop prints were stamped "Approved" or "Approved as Corrected" and signed by the checker, who also added the date of checking. They were then returned with a letter of the form shown in Fig. 58*e*, except where it was necessary to advise more fully regarding the corrections, in which case a special letter was written and enclosed with the form letter. The latter was made out in triplicate by the checker, the original being for the shops and the copies for the Drafting Department and the General Office. These three copies were turned over to the Drafting Room Clerk, together with the prints, which were divided into the office and the shop sets and so marked. The clerk checked the prints against the list given in the form letter, and approved the latter, if found correct, by adding his initials where noted "Approved." The shop prints and the letters were then turned over to the general office for mailing. After this the office prints were recorded by the clerk and filed, as were also the copies of the letters.

All drawings were mailed in duplicate by the shops, until approved; and when approved, final prints were sent in for the files of the Field Engineers, the Shop Inspectors, the Clients, and other parties to whom sets of drawings had to be forwarded. These prints were all stamped

"Approved," and were forwarded with the form letter shown in Fig. 58*f*, being handled in the same manner as the prints returned to the shops.

WADDELL & HARRINGTON
CONSULTING ENGINEERS
KANSAS CITY, MO.

____

____________________ BRIDGE

____

____

SIRS:—We are returning you to-day prints of your drawings as follows:

Contract No.	Drawings Approved	Drawings Approved as Corrected

APPROVED:

____

Yours truly,
WADDELL & HARRINGTON
By ____________________
Chief Draftsman

FIG. 58e. Form Letter Accompanying Shop Drawings Returned to the Contractors.

At the close of the job a final set of cloth prints was obtained from the shop for a permanent record.

A complete record of the shop drawings was kept on the form shown in Fig. 58*g*. These sheets were of the same size and were filed in a folder in the same manner as those for the record of the office drawings. The

drawings were always listed consecutively, and the sets thereof for the various contracts on any job were kept separately. The shops were requested at the outset of a job to furnish a list of their drawings for the

WADDELL & HARRINGTON
CONSULTING ENGINEERS
KANSAS CITY, MO.

____

______________________ BRIDGE

____

____

Dear Sir:—We are sending you to-day, for your file, prints of shop drawings for the above bridge as follows:

Contract No.	Drawings (Give Number of Prints)

Yours truly,
APPROVED: WADDELL & HARRINGTON

.... By................................
Chief Draftsman

FIG. 58*f*. Form Letter Accompanying Shop Drawings sent to Clients, Resident Engineers, Inspectors, etc.

whole work or any section of it at the earliest date possible in order to assist in arranging the record. It was not always convenient to do this; but when it was done, it certainly was a great help to the office.

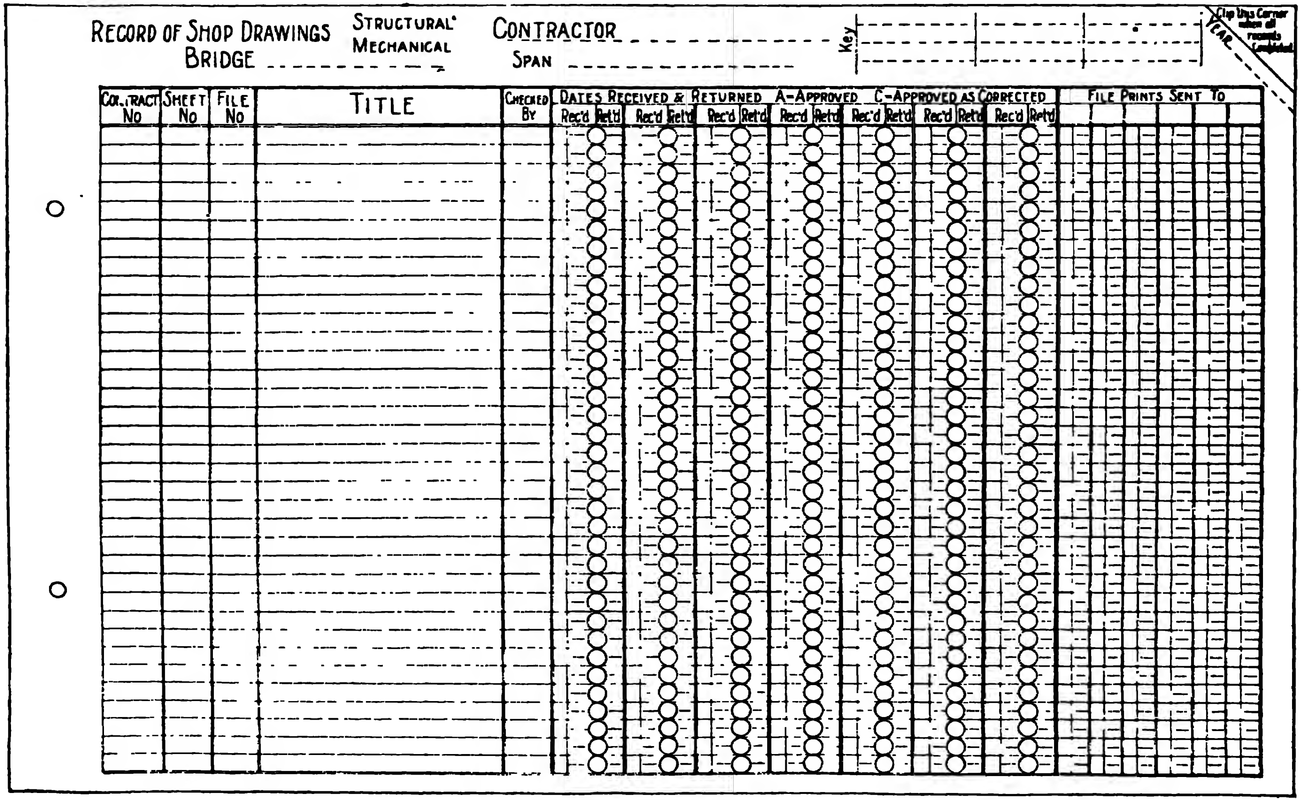


FIG. 58*g*. Shop Drawing Record.

As soon as a set of shop drawings was received, stamped, and sent to the Drafting Department, a file drawer was assigned to them; and the record was filled out as to the name of the bridge, the span, the contractor, the contract number, the sheet numbers, the file number, the title of sheets, the number of prints of each drawing received, and the date of receipt. The last two items were placed in the column following "Checked By," the first in the rectangle and the last just to the left of the circle. The prints were then assigned to the checkers, who looked after them immediately, unless they had more urgent work to get out. It was always planned, however, to attend to the shop drawings just as soon as they reached the office, so as not to hold up the shop work or to give the shops an excuse for claiming an extension of time. To assist in this respect, the clerk went over the records of unfinished jobs each week and made out a list of prints that had been held in the office a week or more. This list was turned over to the Chief Draftsman, who investigated the reasons for the holding up of the work in question and made sure that the checking was not thereafter unnecessarily delayed. A similar list was made of drawings being held unduly by the shops, and a copy of this was forwarded to them with a request that they push the work as much as possible, when the work was likely to get behind.

As soon as the drawings were checked, they were turned over to the clerk, as previously noted. He then inserted the names of the checkers in the key and their initials under "Checked By." In the circle he wrote "A" or "C," depending on whether the drawing was "approved" or "approved as corrected"; and following this, he gave the date on which the prints were returned. When revised prints came back, these were entered in the next column as before, and the clerk delivered them to the checkers, together with the prints of the same drawings previously received. The checking of the corrections was then taken care of, and the prints returned to the shops. This procedure was continued until the drawings were approved. After that, the prints for the various files were sent in by the shops and listed. They were stamped and forwarded to the proper parties, a record being made of the date and the number of prints sent to each at the right-hand end of the sheet under the heading "File Prints Sent To." The year or years over which a record extended were given at the upper right-hand corner of the sheet. After the record was complete, the upper right-hand corner was clipped, as noted, for convenience in referring to the unfinished jobs.

When prints of the office tracings were needed, orders for these were made out in duplicate on the form shown in Fig. 58*h*, consisting of a pink sheet $8\frac{1}{2}'' \times 11''$ in size. This form gave the number and kind of prints of each drawing wanted. They were placed in separate baskets—one for the blue-printer and one for the Drafting Room. The blue-printer took his copy, picked out the tracings, and made the prints. He returned the copy, together with the prints, to the clerk, who made sure that the latter

corresponded to the order. When the prints were wanted by someone in the office for his own use, they were delivered directly to him; and one copy of the order was destroyed and the other filed in the drafting room. In such cases the order had to state clearly the purpose of the prints. When the prints were to be sent out of the office, they were prepared for mailing and then turned over to the General Office, together

DATE........................

TO THE CHIEF DRAFTSMAN:

PLEASE FURNISH THE FOLLOWING PRINTS:

WHEN WANTED.........................ORDERED BY......................

THE ABOVE PRINTS ARE DELIVERED HEREWITH.

DATE........................

SIGNED.................................

TO THE MAILING CLERK:

THE ABOVE PRINTS ARE:

PRINTS MAILED—DATE............................

SIGNED.................................

FIG. 58*h*. Order Blank for Blue Prints.

with the duplicate of the order, properly signed. The original order was filed in the Drafting Room. In preparing prints for mailing in envelopes, they were always folded so that the titles appeared on the outside. When a great number of prints were ordered at one time, the more important orders were, of course, attended to first. This was looked after by the clerk, who saw that the prints were gotten out as quickly as possible.

In addition to filing the orders, a record was kept of all prints sent out of the office. These were listed on the form shown in Fig. 58*i*, which was of the same size as the standard calculation sheet and was kept in a similar folder. A record was made out for each job; and these records were filed alphabetically according to title. The sheet numbers were listed complete and in numerical order, even though prints were not made of all of them. The initials of the party to whom the prints were

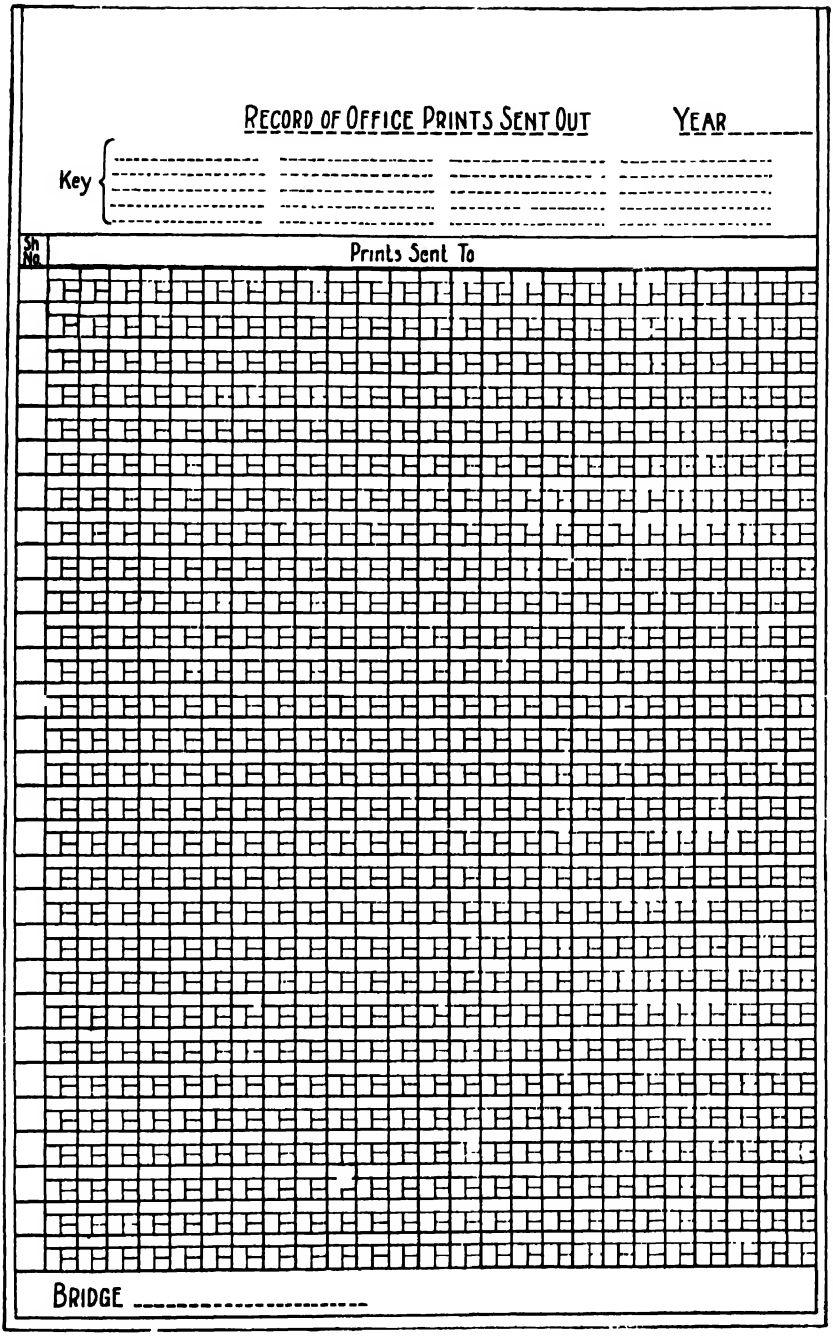


FIG. 58*i*. Record of Office Prints Sent Out.

sent were placed in the top rectangle, the number of prints below to the left, and the date just to the right. The key gave the full names and the corresponding initials used in the record. The year or years were given at the top of the sheet, and the name of the job at the bottom. These records were made directly from the orders at the earliest convenient time after the prints were sent out.

TIME CARD

NAME.................................DATE..........................

Job No.	Sheet No.	Work	Hours	Remarks
Total				

FIG. 58j. Daily Time Card.

To facilitate the handling as well as the making of complete records of the work, the time card, 3″ × 5″ in size, shown in Fig. 58j, was used. Each draftsman handed in a card each day, noting upon it the jobs he had worked on; the sheet numbers of the drawings; the section numbers of the calculations; the contract numbers of shop drawings; the nature of the work as to making, tracing, checking, back-checking, correcting, and revising; the time spent on each; and any remarks that might be necessary to give a complete record. In all cases in the "Remarks" column it was noted when a piece of work was started or completed. The time was recorded each day by the clerk on the "Monthly Time Card," shown in Fig. 58k. These sheets were 8½″ × 11″, punched for a loose-leaf holder. One sheet was assigned to each job, and these sheets were filed according to the job numbers. The time per man per job was totaled at the end of the month; and these totals were added together and checked against the total time of each man taken from the daily time cards. The monthly time cards were handed in to the General Office for cost distribution. The daily time cards were filed in the Drafting Department.

JOB NO. MONTHLY TIME CARD MONTH

HOURS WORKED BY

Date																														
1																														
2																														
3																														
4																														
5																														
6																														
7																														
8																														
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28																														
29																														
30																														
31																														
Hours																														
Dollars																														

Total monthly cost

Distribution of drawing room office time

Grand total monthly cost

FIG. 58*k*. Monthly Time Card.

The daily time cards were also used in making up the time records for the Calculations, Drawings, Shop drawings, Weights, Estimates, and Layouts. These were prepared on the forms shown in Figs. 58*l*, 58*m*, and 58*n*. The cards for "Weights," "Estimates," and "Layouts" were similar to that for "Shop Drawings." A like card was also used for the time spent on a job that could not be assigned to any definite item. This

CALCULATION RECORD

JOB NO..................

SECTION.................. YEAR...............

MAKING	CHECKING	BACK CHECKING	REVISING	CHECKING

FIG. 58*l*. Time Record for Calculations.

was listed under the heading "General." These cards were all filed in numerical order, according to the job numbers, in a standard filing case.

Various files and indices for them were maintained in the Drafting Department. Four of the six drawers in the drafting tables were used for filing, in addition to the cases made specially for that purpose. The Drafting Room Clerk was in charge of all of these. Capital letters were employed to distinguish the different files, and the drawers in each were numbered.

The Record Drawings were filed in the drafting tables. These consisted of all drawings containing data or information of any nature whatsoever sent to the office by clients, field engineers, and others. On account of the irregularity in the sizes of the sheets, they were filed rolled, all drawings pertaining to one job being placed in one or more rolls, depending on the number of prints. Data drawings referring to a particular bridge were separated from those of a general nature which might refer to a number of bridges. Each roll in the drawer was given a different number and each drawing in the roll a letter. Thus R16 5c meant drawing "*c*" in roll "5" in drawer "*R*16" of the "Record File." This file number was written on the back of each drawing at both ends. The index for the record file was made out on cards 3″ × 5″ in size. White cards were used for the drawings referring to a particular structure, while pink ones were employed for those containing general information only. The drawings were listed under the name of the river or detail, and cross-referenced under the name of the client, city, and street. The information given on the main card was always sufficient to designate the drawing for reference. In using any drawing, the whole roll was taken out of the file by the person wanting it. This was returned to the clerk, who saw that the roll was complete and in order; and then he replaced it in the file.

DRAWING RECORD

JOB NO............ SHEET NO............

DETAILING	TRACING	CHECKING	BACK CHECKING	CORRECTING	REVISING	CHECKING	CORRECTING

FIG. 58*m*. Time Record for Office Drawings.

The calculations were filed in folders, as noted previously. The proposed and the final jobs were placed in separate folders, the former being marked PB1, PB2, etc., and the latter C1, C2, etc. A number of small bridges were filed together in the same folder, while the very large ones

were divided among several folders. This was gauged by using a maximum thickness of one and one-half inches to one set. The divisions arranged by the Chief Designer were maintained in the filing. A complete list of these sections and the sheet numbers were given at the beginning of the calculations. In the folders for small bridges, each set of calcula-

SHOP DRAWINGS

JOB No............ YEAR.............

FIG. 58a. Time Record for Shop Drawings.

tions was tabbed and labelled; in the large bridges, the main divisions, such as "Substructure," "Spans," "Towers," etc., were likewise tabbed and labelled. The calculations were indexed under the name of the river or main subject, and cross-indexed under the name of the client, city, and street. Only the number of the folder and that of the main division, in case several folders were assigned to a single job, were given. Standard 3″ × 5″ index-cards were employed.

The tracings for the regular detail drawings were filed flat in drawers

in a case made specially for the purpose; while those of the sketch sheets were put in a standard vertical letter file. The former were placed in paper envelopes about ten to each drawer, each envelope containing about ten tracings. These were arranged in numerical order; and on the envelopes were printed the title of the job and the numbers of the drawings they contained. The mechanical drawings were kept in a separate section of the cabinet. All void tracings were placed in a separate folder at the bottom of the drawer, so that only the final drawings appeared in the regular file envelopes. Proposed jobs were kept separate from the final jobs in a special section of the case. Small miscellaneous jobs and miscellaneous sheets were likewise filed in special drawers. At times it was necessary to make extra long drawings for the "General Layout" of certain structures, and these were rolled and placed in special drawers separate from the rest of the set. The small sketch sheets were filed in paper folders in alphabetical order according to the name of the job. While the draftsmen were permitted to remove tracings from the files, they were not allowed to return them. Instead, they were placed in a special drawer, assigned for the purpose, from which they were taken and properly distributed each day by the clerk. This was done in order to hold the clerk responsible for the order of the files.

The index for the tracing file was made out on the standard 3″ × 5″ cards. The jobs were listed under the name of the river or the principal subject, and were cross-referenced under the name of the client, city, and street, and also under any other heading by which it might be recognized. The drawings were all listed and grouped under the following classifications: General Drawings, Substructure, Stress Sheets, Superstructure, Miscellaneous, and Void. Maps and General Layouts were recorded under "General Drawings"; while all miscellaneous details were included under "Miscellaneous." On large bridges the above classifications were still further broken up according to the main divisions of the structure. The cards for any job were not made out until after the drawings were completed.

The Checking Prints were folded and put away in a vertical file until the shop drawings were checked, after which they were destroyed. They were kept in alphabetical order, but no index was provided for them. Prints sent to the clients for approval were filed in a similar manner when returned. They were destroyed after the job was finished and completely settled for. When prints were sent out to bidders, an identical set was filed in a vertical filing case and kept until the structure was completed. They were then destroyed. They were used in case a dispute arose regarding the plans upon which the bids were based.

During the construction of a job, the Resident Engineer sent to the office records of the structure as actually built. These were kept in a vertical filing case. At the end of the work a drawing was prepared

showing the actual construction; and prints of this were sent to the client as a record.

The shop drawings were filed in the table drawers under the various jobs and contract numbers. They were arranged in consecutive order, only the latest prints being placed in the final set. All void or replaced prints were filed together in proper order at the bottom of the drawer. All prints were kept until the job was finished in the field and all claims settled. They were then destroyed, all except the cloth set, which was filed permanently. Shop bills and small sketch sheets were placed in a vertical filing case and handled in the same manner as were the regular shop drawings. The draftsmen were permitted to take the shop drawings from the files; but, just as in the case of the tracings, the clerk returned them in proper order. A card index was provided for the shop drawings. The jobs were listed under the name of the river or principal heading; but cards were made out only for the various contracts; and under each a complete list merely of the drawing numbers was given. Only the titles of the main divisions of the structure were noted. For more detailed information, the "Record Book for Shop Drawings" was consulted. A file for specifications for current jobs was kept in the Drafting Room, but no record was made of these, as the General Office had charge of the permanent file.

Copies of all correspondence in relation to drawings were filed in paper folders under the various jobs. When any job was completed, the special correspondence for this was destroyed. A vertical filing case was maintained for all rulings or special instructions made by clients.

All catalogues from manufacturers were filed in the Drafting Department; and a complete index was made for them.

The General Office was in charge of the library, and requisitions had to be filled out in order to secure library books. The person signing these was held responsible for books taken out until they were returned.

Further information of value concerning office practice can be found in Chapter VII of Skinner's valuable work on "Plate-Girders," and in Davies's excellent treatise on "Engineering Office Systems."

CHAPTER LIX

INSPECTION OF MATERIALS AND WORKMANSHIP

BEFORE commencing to prepare this chapter, the author took the precaution to write several of the leading inspecting bureaus of the United States and ask them for comment on Chapter XXI of *De Pontibus*, which also treats of the subject herein considered; for he knew that during the eighteen years which had elapsed since that book was written many important developments in American methods of inspection had taken place. The result was the accumulation of much valuable material concerning the inspection of metalwork from such high authorities as Messrs. Hildreth & Co., the Pittsburg Testing Laboratory, Messrs. Colby and Christie, C. C. Schneider, Esq., C.E., E. McLean Long, Esq., C.E., and Robert W. Hunt and Company. This has been utilized in recasting that portion of *De Pontibus* relating to metal and metalwork inspection; and the author here takes the opportunity to express to those gentlemen, individually and collectively, his sincere and hearty thanks for their kind cooperation and valuable aid. In some places he has quoted verbatim from their contributions with the usual due acknowledgment, but in others he has applied the information and suggestions directly to the modification of his own previous writings.

Unless all the materials used in a structure and all workmanship during the various stages of manufacture at the shops and of construction in the field be subjected to competent and honest inspection, much of the benefit obtained by scientific design and thorough specifications will be lost. For many years most of the inspection of structural metalwork was a sad farce; and, in consequence, the general public placed but little confidence in inspection, with the result that a large portion of the bridgework of the country was left entirely to the tender mercies of the manufacturers, who naturally worked for their own interest and not for that of the purchasers. Of late years, however, improvements in inspection methods have been made by a few of the leading specialists in that line of work; but, sad to relate, there is still a vast amount of slip-shod inspection being done at rolling mills and bridge shops, mainly because purchasers of metal are not willing to pay a proper compensation to the inspectors. In times past the author suffered considerably from bad inspection in such matters as the insertion of a rust-joint in a turntable between the bottom of drum and top of upper-track segments, where no such filling was allowed in either plans or specifications; badly matching holes in field connections; pin-holes too small for pins; important members

omitted in shipping; eye-bars made longer than called for by the drawings; great recesses in webs and fillers at ends of girders; and shop-paint applied over half an inch of frozen mud. Such things, to say the least, are extremely annoying, and often cause great expense during erection. But of late years he has adopted the policy of having all of his metalwork inspection done by one firm, with the result that all the glaring deficiencies of that class of engineering work have been cut out, probably because of the fact that the annual amount of structural steel emanating from his firm's office has amounted to many thousands of tons, and, in consequence, the inspecting bureau did not want to lose a good job.

Inspectors are by no means entirely to blame for the fact that the inspection of structural steel in general is not what it ought to be; because back of them are the railroad managers and promoters of large enterprises, who do not recognize the necessity for first-class inspection, and who are often not willing to pay one-half of what such inspection is worth. Here again, though, the inspectors are to blame, for the reason that in the keenness of their competition for work they have cut prices to such an extent as to make it impossible to do proper inspection without losing money. When pinned down to facts they have to confess this. The coolness of some of the "small fry" inspectors is often amusing. The author was once hauled over the coals by one of this class who had put in a low bid for some inspection, and whose tender had been rejected because of the low figure, the work having been awarded to one of the regular inspecting bureaus at about fifty per cent more than the unsuccessful bidder asked. After expressing his mind pretty freely, he fired this parting shot: "Well, I never intended to do thorough inspection for you, anyhow."

The inspection business has been utterly demoralized in times past by just such action as that contemplated by this inspector; for it was the general custom, and is yet to a certain extent with some inspectors, to take contracts for inspection at whatever figures the purchasers are willing to pay, then handle the work so as not to lose money on the contract, regardless, of course, of the interests of their employers. Strange tales concerning inspection come to the ears of engineers—such, for instance, as passing car-load after car-load of metalwork that was not seen by the inspector until after loading for shipment; but such tales need verification, which, of course, it is nobody's business to give. There is no doubt, though, of some of them being authentic. In one case in the author's experience the inspector left his work for ten days in charge of one of the bridge company's shipping-clerks, without notifying either the author or his direct employers, the inspection bureau, of his contemplated absence. Such actions as this make one entertain serious doubts sometimes as to whether inspection really pays.

It is possible that the general demoralization of metal inspection by insufficient prices and keen competition has lowered the quality thereof

to such an extent that even the highest possible prices would not make it, for some time to come, what it ought to be; because not only are the assistant inspectors lacking in proper training and thoroughness, but the manufacturers have become accustomed to a certain class of inspection, and would deem it a hardship to be subjected to much more rigid requirements. Eventually, however, the resulting improvement in manufacture of metalwork would be an advantage to the manufacturers as well as to the purchasers.

A decided betterment of inspection can be brought about only by concerted action on the part of the principal inspecting bureaus and inspectors of the country, backed, of course, by the aid of all engineers who are directly interested in the designing and building of structural metalwork. If these inspecting bureaus and inspectors of established reputation were to form an association for the purpose of determining what inspection should consist of, and what minimum rates should be charged therefor by all members of the association, and if admission to the association were based upon both experience and good faith, it would be practicable to make very quickly the improvements requisite for bringing inspection up to an almost ideal standard of excellence. For a while a good deal of work would go to the inspectors outside of the association; but ere long the general public would become educated to the fact that good inspection of metalwork is a necessity, and that it can only be obtained by paying living prices to those who do the work. Engineers, in order to aid in the good work of the association, should refuse to include the price of inspection in their fees for engineering work, and should make it a rule to employ for doing their inspection only members of the association.

Certain engineers of high standing have spoken slightingly of this proposition to form an association of inspectors, terming it a "trust." Strictly speaking, it certainly would partake of the nature of a trust, but it would be a good and worthy one, the main object of which would be to effect a much needed reform. On the same basis the American Institute of Architects is a trust, for the reason that it establishes a minimum fee of six per cent for the making of plans and specifications and sometimes also for the services of an inspector on all building work; and surely such an organization should not be condemned on this account. On the contrary, the architects have set the engineers a good example in forming this association; and, until engineers follow their lead in this particular and establish minimum fees for professional work, the engineering profession will fail to attain its highest degree of efficiency, and will, therefore, not be properly recognized as a profession by the general public.

In order to present the inspectors' views on the subject of metalwork inspection, the following quotation is extracted from a communication by Messrs. Hildreth & Co.:

"REASONS FOR INSPECTION

"Good engineering practice has established the necessity of the supervision of engineering work during its entire progress. The supervision of the manufacture of structural metalwork is as essential as that of checking the design and the plans or supervising the work in the field. Such supervision is rarely necessary as regards the management of the manufacture. It is fair to assume that all manufacturers operate their business with the intent of giving good value under their contracts; and no manufacturer could long exist if he carried out the policy of constantly and intentionally evading his contract obligations. However, when the details of manufacture are considered, it should be appreciated that practically all work is piece-work, and is done by workmen who have no strong personal interest in the high character of the work turned out. They are not only careless, but they have a personal incentive to do their work hurriedly and are under constant pressure of their superiors to 'get out the tonnage.' It is work as done by the workmen that requires thorough and careful inspection; and it is fair to state that the attitude of the managements of a great majority of manufacturers is to support such inspection, when it is done by an intelligent and experienced inspector who so adapts his inspection as to discover defects and errors as early in the work as possible, and who co-operates with the management as to the output of good work with the least expense to the manufacturer.

"An important feature of the supervision of manufacture is the value of having a representative at the points of manufacture, whereby the progress of the work is known and the shipment of the finished product can be had at the time and in the order necessary for expeditious and economical erection.

"A further reason for such supervision by inspection is in having a record whereby the quality of material and workmanship is attested to and may be useful in placing the responsibility for subsequent possible failure or in relieving from responsibility those interested who should properly be relieved from the same. It is not inconceivable that an Engineer or Architect who fails to provide for the supervision of manufacture may be held responsible for damage or loss of life resulting from any failure at erection or thereafter.

"FUNCTIONS OF THE INSPECTING ENGINEER

"Supervision of the manufacture may be made by employees of an Engineer or Architect or by the employment of Inspecting Engineers who make a specialty of such work. The reasons for the existence of the latter are primarily that the manufacture of structural metalwork is conducted at various rolling mills and at one or more fabricating plants, is in progress at several points at the same time, and is frequently intermittent. If an Engineer or Architect uses his own employees for this work, it is essential that several men be employed; and there is, consequently, much waste of time and of traveling expenses. To meet this situation, the independent Inspecting Engineer establishes an organization of experienced men who are permanently located at the various manufacturing centres, and, by competent supervision of their work, makes use of their time over a number of contracts, thereby tending to efficiency and economy. Such a concern, presumably, has a wide knowledge of shop methods and a personal acquaintance with many shop managers, and from experience is able to handle the defects arising during manufacture with some advantage of practical knowledge, as compared with the designing Engineer, and has personal acquaintance and constant business relations with the shop management.

"It should be appreciated that inspection is not insurance. The inspector is not responsible for the design, specifications, sufficiency of tests, or the shop management, but is an expert witness whose duty it is to see and report conditions and to conduct supervision in such a manner as to improve the character of the materials and workman-

ship, and give an accurate record thereof. The responsibility for compliance with plans and specifications and general good practice rests primarily with the Contractor. The responsibility of an inspector is for intelligent and faithful supervision and accurate record in accordance with the established and specified practice of tests and standards of workmanship.

"The position of the inspector is that of an employee to the Engineer or Architect, who, when he uses such employee, is himself Inspection Engineer as well as the designer and supervisor. If Inspecting Engineers have charge of the work, they are the Associates of the Engineer or Architect in something of a professional capacity. In either case the quality of inspection is evidently dependent, as is all professional work, upon the character of the men on the work; and it is unavoidable that the character of the men is dependent upon the compensation allowed.

"Quality of Inspection

"From the above it will be appreciated that the quality of inspection must, according to the same rule as applies to all business, be in direct proportion to the compensation. To be of genuine value, inspection must be constant, intelligent, and complete. A final inspection may determine the satisfactory compliance with the contract, but cannot, generally, secure the satisfactory correction of errors, and certainly cannot prevent them or tend to the improvement of the work. The tests of quality of inspection are the experience of the men directly on the work, the time spent on it, and the quality of the final record. These tests apply equally to the work of direct employees and to that of Inspecting Engineers. The latter may properly make a profit from the favorable combination of work at rolling mills and fabricating plants or manufacturing shops, and from the saving of time and traveling expenses; but any profit from the neglect of work by insufficient attention or from the employment of underpaid employees is improper. The Architect or Engineer, if he desires to secure the best inspection by Inspection Engineers, should decide upon the experience and reputation of the firm with whom he proposes to deal, should know the experience of the men to be employed upon the work, and should critically examine the character of the record furnished him. He may properly demand information as to the time of the men employed upon the work.

"Methods of Payment

"The usual method of payment for inspection services when done by Inspecting Engineers is at a price per ton. This always should be per ton of material or workmanship inspected and not per ton accepted, for the reason that it is undesirable to put a premium upon the acceptance of work which may be defective or doubtful. With knowledge as to the quality of inspection, as noted above, the method of payment by tons inspected is satisfactory; but if an Engineer or Architect is doubtful as to the character of the work that is to be done, he may arrange his terms on a basis of the cost of the actual time of the men employed on the work, plus a percentage to the Inspecting Engineers for organization and supervision. The last course he should take is the placing of inspection work under competition to the lowest bidder. Such a course must mean not only his willingness but his demand for the least attention by the lowest salaried men available. This method is a favorite one followed by Purchasing Agents of large corporations; and it is invariably unsatisfactory. A moment's consideration will convince any one that the proportion of profit to inspectors must remain the same or increase, whereas the proportion of loyalty and conscience must diminish. Payment for inspection is not a part of the obligation of the Engineer or Architect, but is that of the Owner. The strong Engineer or Architect will not evade this question, but will either demand that the Owner make such provision and leave to the Engineer or Architect the right to choose his associate; or he will provide in the specifications that the

inspection shall be paid for by the Contractor as a part of his work, but shall be arranged for by the Engineer or Architect at a specified price, and that the Inspectors shall be responsible solely to the Engineer or Architect."

The following are the author's general instructions to his inspecting bureau concerning the inspection of metalwork at mills and shops.

First. Study carefully the Engineer's drawings as soon as they are finished, and make out a list of special points and features that will require extra care in the shops to secure good workmanship and proper fitting, then prepare a typewritten report of these and submit it without delay to the Engineer.

Second. Study carefully, as soon as they are finished and approved, all shop drawings, so as to become thoroughly familiar with the entire construction.

Third. Make sure that metal of uniform character and of the strength, elasticity, and ductility specified is furnished by the rolling mills, following the metal from one process to another from start to finish, and making sure that the test-pieces broken represent correctly the metal they are supposed to represent.

Fourth. Check the chemical analyses of the metal occasionally, so as to see that they are properly made, taking care that the Contractor is informed as to what piece the samples are taken from, so that he can make a check test, if he so desire.

Fifth. See that all the various tests indicated in the specifications are made faithfully, the number of same depending upon the relative uniformity of the metal furnished.

Sixth. Make sure that all the punching is done with such care that the assembled parts will come together so as to cause the rivet-holes to match so accurately that when the reaming is finished there shall be no irregular holes.

Seventh. Make sure that all pieces are cut to exact length and proper bevel, that all web-stiffening angles bear perfectly at top and bottom against flange angles, and that there are no loose rivets.

Eighth. Wherever rivets with flattened heads or countersunk rivets are called for, make sure that they are properly chipped or otherwise brought to correct dimensions; also see that the ends of all members are limited to the lengths beyond the last rivet or pin hole shown on the drawings. Give particular attention to the ends of all posts and chord-members to see that the "over-all" and the clear dimensions between jaws correspond faithfully to those indicated on the drawings.

Ninth. Take some effective means of ensuring that the entire work shall go together properly and without difficulty during erection, and so that when completed it shall conform in every particular with the Engineer's design, even if, to accomplish the same, it be necessary in special cases to assemble the entire work at the shops.

Tenth. Watch carefully the punching and the handling of the metal

in the shops, so as to see that no cracks develop therein, and that it withstands properly the manipulation, showing as perfect homogeneity as is found in the best structural steel.

Eleventh. Condemn, as soon as it is discovered, any material unfit in the slightest degree for use in the structure, no matter how many times it may have already been inspected and passed.

Twelfth. See that all metalwork is properly cleaned by the most approved methods and apparatus before the first coat of paint is applied, and that the latter is allowed to dry thoroughly before the metalwork is loaded on the cars for shipment. It is of vital importance to the life of the construction that the metal be cleaned effectively and thoroughly dried before applying the paint; and the Inspector should at all times use the utmost vigilance to make sure that this is accomplished.

Thirteenth. See that all shop painting is thoroughly done, and that proper paint, mixed so as to comply with the specifications, is invariably used; and make an occasional chemical analysis of the paint, taking care that the Contractor is notified of the contemplated test after the samples are taken, in order that he may make a check analysis, if he so desire. Take special care to prevent any pieces of metal from being riveted together, unless the contiguous faces be first thoroughly painted.

Fourteenth. Should any employee of the Manufacturing Company wilfully violate or continue to violate the specifications or the instructions of the Engineer or his Inspector, bring at once to the attention of the said company the fact of his so doing and request that he be discharged from the work in question; and if the request be ignored, report fully in writing or by telegram concerning the matter to the Engineer.

Fifteenth. While endeavoring in every possible way to obtain good work, avoid as much as possible doing anything to annoy or harass the Contractor; but, on the contrary, take special pains to aid him in every legitimate manner to finish his work quickly and inexpensively.

Sixteenth. Formulate and prepare for each large piece of work the best practicable method of recording progress and reporting thereon, and divide up the total work into groups or sections so that the notes may be easy for reference. This should be done by the inspecting bureau, and should not be left to the shop inspector.

Seventeenth. Send into the office of the Engineer regular weekly reports concerning the progress of the work, any special reports that from time to time appear to be required, the tabulated results of all tests of materials, and copies of all shipping bills.

Eighteenth. Make sure that all shipping weights are correct by seeing the metal weighed, and keep account of the weight of all metal sent out on the work, as the Contractor will be paid by the pound. It will be necessary for the inspecting bureau to check all of these weights against the shop drawings to show how they agree or disagree. A detailed statement of both sets of weights must be sent to the Engineer upon the com-

pletion of the contract, or at his request, upon the completion of any definite portion thereof.

Nineteenth. The inspecting bureau shall, under no circumstances whatsoever, entrust responsible work of any kind to insufficiently trained assistants. When new inspectors are to be broken in, they must receive their training in such a way as not to jeopardize in the slightest degree the quality of the material or workmanship.

Twentieth. Finally, and in short, do all you can to make the structure in every sense of the word a credit to all concerned in its designing and construction.

The preceding instructions are those from a consulting bridge engineer to his inspecting bureau, and are of a more general nature and, necessarily, much less detailed than those from such a bureau or an inspecting engineer to assistants in the rolling mills and bridge shops. In order to illustrate the latter, the author, notwithstanding the risk he thereby may run of being accused of a certain amount of repetition, reproduces in full the excellent instructions of Mr. Long to his assistants at mills and shops, also the equally good ones of Messrs. Hildreth & Co., and of Messrs. Robert W. Hunt & Co., and supplements them with certain extracts from similar instructions by Messrs. Colby & Christie (as prepared by their consulting engineer, Mr. Schneider). A perusal of all these instructions ought to suffice to post the reader thoroughly as to all the important details of metal inspection at rolling mills and bridge shops.

Mr. Long's instructions read as follows:

"In the inspection of mill and shop work the Inspector should know what faults to look for, and how, where, and when to find them. He should be thoroughly conversant with the methods of the shop or mill in which he is inspecting, and should arrange his inspection so as to follow the work in all stages of its progress and know what is being done in every department.

"The sooner he detects defective material or bad workmanship, the better it is, and the easier is the remedy. He should make a point of knowing the duties of the different men in the mill and shop; and he should take up points relative to his work rejections or improvements with the proper persons and in the proper way, and should see that all necessary orders are given and carried out.

"MILL WORK

"1. *Study of Specifications.*

"Study carefully the specifications for character of steel, and mark anything in them that is unusual or liable to cause extra work on the part of the mill to live up to. Consult with the Engineer or main office on such points, and have a clear understanding of what is wanted before the work begins.

"Make an abstract of the specifications, showing physical and chemical requirements, and tests demanded by the Engineer for the determination of the same. This abstract should be copied in the Inspector's note-book for ready reference.

"2. *Order Sheets of Material.*

"The draughting room should supply the Inspector with a copy (in duplicate) of order sheets of material, containing estimated weights and all information necessary

to enable the mill to fill the specifications. When the Inspector receives these, he should see that the proper information is on them; and he should look over them in connection with the drawings, and should note on the sheets in what part of the structure the material is to be used. A good many draughting rooms make a practice of putting on each order sheet the part of the structure for which the material is intended. This is a good practice; it gives the draughting room very little extra work and facilitates the checking of the material and reference thereto.

"The Inspector, by knowing where material is to be employed, is in a position to use some discretion, and he will not reject material such as filler plates, stiffeners, and the like on account of their being slightly out in some of the requirements. Work is often needlessly delayed and great inconvenience occasioned by the rejection of material that is better than the work it has to do requires. On the other hand, he will mark on the order sheets the material on which the life of the structure depends, and will insist on its filling the requirements in every respect.

"3. *Know the System of the Mill.*

"The Inspector must know the system of work of the mill, and must satisfy himself that the methods employed are such as to prevent the mixing of heats, and that they will insure the knowing of the heat of the finished material. Some mills keep a very close and exact track of all heats used, while others are inclined to be careless. If the methods employed by any mill are not sufficient to keep the heats straight, the Inspector should work with the Superintendent to better his system, or should follow this part of the work closely himself, so as to insure the accuracy of final results.

"4. *Selection of Tests and Identifying Material.*

"The Inspector should determine from the mill what material for his work is rolled from each heat, and should then select tests so as to represent the different sections rolled; for the working of the steel greatly affects the physical properties of the finished bar, thick metal giving different results from thin.

"It is the Inspector's duty to know that tests for the material are cut from sections of the same heat that they represent. All finished material should be stamped with the heat number of the steel from which it is made; and when the material is cut up, these numbers should be reproduced on the shorter lengths. The heat from which a piece is made can then be identified at any time.

"5. *Making Physical Tests.*

"The Inspector should see that the test pieces are properly prepared and of the size required.

"*a.* Tensile Tests: In test for ultimate strength and elastic limit, the Inspector should satisfy himself that the machine is correct and that it is properly operated. He should check the dimensions for the determination of elongation and contraction, and should always observe the fracture. In case a test piece should fail on account of a local defect, or on account of breaking in the grips of the testing machine, a retest should be allowed.

"*b.* Bending Test (Cold): The bending of test pieces can be performed in the way most convenient to the Manufacturer, but they must be flattened down to the amount required in the specifications.

"*c.* Bending Tests (Quench): In the case of quench-tests, the Inspector should see that the specimens are heated properly and that the water for quenching is of the specified temperature. The intention of this test is to show whether the steel, in case it should be heated to a red heat and suddenly cooled, would become so brittle as to render it unsafe. In some cases this test tends to water-anneal the steel; but, as a rule, it hardens it. If this test be conducted improperly, the steel will be either annealed or rendered worthless.

"*d.* Hot Tests: In the case of hot tests the Inspector must see that the metal is at the specified temperature while being bent or hammered.

"*e.* Drift Tests: In making drift tests, the hole should be punched at the specified distance from the edge of the piece to be tested, and a drift pin of proper taper should be used.

"*f.* Special Tests: Other tests, sometimes required, such as opening and closing tests, flattening tests, breaking tests, torsional tests, impact tests, fracture tests, etc., must be made in strict accordance with the specifications.

"6. *Chemical Tests.*

"The mill should supply the Inspector with a full chemical analysis of each heat, which he is at liberty to check at any time by making his own analysis. In case check analyses are taken, the Manufacturer should be allowed to make analyses from the same drillings as used by the Inspector. When the specifications require chemical analyses of the finished material, the drillings for these analyses should be made, in the presence of the Inspector, from one end of the fractured tensile test piece, and the Manufacturer should be allowed to make analyses from the same drillings.

"7. *Report of Tests.*

"After all the material for an order is rolled and tested, the report of tests should be made in such a form that it can be easily referred to, and so that the material used in any part of the structure may be identified.

"8. *Surface Inspection.*

"The amount of inspection given in the mill is controlled to a great extent by the specifications. Some specifications require the watching of the steel from the time the raw material is put into the reducing furnace until it gets its final shape, and that after it is rolled to its final shape each bar is to be turned and examined and the heat number identified. For the turning of material all mills have combined on charging $2 extra a ton.

"If each individual piece is not examined, each section should be inspected, to see if it has been rolled true and to gauge, that all fillets are well formed, that the web is smooth and free from buckles, and that there are no lumps or unevennesses (due to defective rolls) which will interfere with the assembling. This inspection insures the section being good, and that individual defective bars will be seen and rejected during the shop inspection. In case bad bars are seen while inspecting material in lots, they should be thrown out at once; and if there are many bad bars, either all the material should be rejected or each individual piece should be turned and inspected.

"9. *Inspector's Note-Book.*

"At the top of the page put the name of the structure, and under this the order number or any other numbers that may be useful for reference. Then write an abstract of the specifications. Leave the remainder of the page and the next page blank for any special remarks or modifications of the specifications. On the following pages make a classified list of material required; the different sections being placed in a column on the left side of the page, with the remainder of the page to the right blank for inserting progress data, such as: Scheduled time for rolling, date of tests, heat numbers, etc. When all the material of a required section is rolled, run a pencil line through the item.

"The advantage of a well kept and simply arranged note-book is to add system to the work of inspecting, and to enable the Inspector, at any time, to know the exact condition of the work in the mill.

"10. *Checking and Recording Shipments.*

"When material is shipped from the mill, the Inspector is to check the shipments and is to receive copies of the shipping bills, containing sections, weights, lengths, and

heat numbers. After assuring himself that these bills are correct, the Inspector is to check off on the order sheets the material shipped, and is to put on them the heat numbers and date of shipment, and then is to compare the actual weights with the estimated weights in order to see that the material is rolled within the allowable weight limits. By referring to the order sheets at any time the Inspector can determine what has been shipped and what is still due on the order; and when the order is completed, he has a full account of the heats used and the amount of material in each heat.

"11. *The Inspector should not allow any material to be shipped until after it is tested.*

"12. *Reports.*

"Reports of mill work must be made at the end of each week and should state:
Total estimated weight of material on order.
Total estimated weight of material rolled or shipped.
Total actual weight of material rolled or shipped.
Sections rolled and tested and weight shipped during the week.
What sections are expected to be rolled during the following week.
Remarks...................

"In cases where engineers want reports in different forms, the character of the reports must be changed as required.

"SHOP WORK

"1. *Study of Blue Prints.*

"Before the shop work commences the Inspector must be provided with a set of prints, approved by the Engineer in charge of the work. On the receipt of these, he must first study the general plans and obtain a clear idea of the structure in its entirety. He must then study carefully all points and details in connection with the specifications and see that all notes on prints agree therewith; for these notes are the instructions to the shop as to how the work shall be done. He should make a memorandum, to be submitted to the Engineer, of all points of disagreement between drawings and specifications. He should also, in studying over the details, make notes on the prints of any points where difficulties in construction are liable to arise, and of such details as must be absolutely correct, and should devise methods of checking and insuring their accuracy. In cases where standard connections are not used (in beam and angle work), he should make a mark on the print to emphasize that fact. Where sections are given in pounds per foot, he should put on the print the thickness, so that he can check up the said sections during inspection. He should note on the prints the clearances allowed so as to be sure that the work will go together properly.

"2. *Preparing Material for Shop Work and Laying out Work.*

"All sections should be straight before any work is laid out to template. The templates should be made of at least ½" plank; and in cases where a template is built up, the different parts should be securely fastened together, so that there is no chance of its getting out of shape. When a member is being laid out, the templates must be in true alignment and firmly clamped to it. The center punch should fit the holes in the template snugly; and it should be hit with sufficient force to make a well defined centre mark. When the template is removed, all centre marks should be marked with white lead, and the location marks should be put on the member.

"3. *Punching.*

"The difference in size between the die and the punch should not exceed the following limit: $^1/_{16}$" for punching metal up to ½" thick, and $^3/_{32}$" for thicker metal. The punch and die should be well formed and smooth, and the punched holes should be free from jagged edges and excessive burring.

"Where reaming is not called for, the material should be so punched that the burr end of the hole, wherever possible, will be on the outside after assembling. Where reaming is called for, the burr end of the hole is to be considered as the punched diameter of the hole.

"During the process of punching the Inspector can detect any lack of uniformity or undue hardness of the metal by the way it punches, and can also determine whether the steel is being cracked or injured. Any sections that have been bent by punching must be straightened, and any bad burrs or roughness of the section that will interfere with assembling must be chipped off.

"4. *Assembling.*

"Before any work is assembled the Inspector must see that abutting surfaces are cleaned of lumps, rust, and dirt, and that they are well painted with the specified paint, and also that all surfaces that will be inaccessible after assembling are properly cleaned and painted. He must bear in mind that this is the only protection these surfaces will ever receive, and that the proper painting of them is of more importance than the outside painting, which can be recleaned and painted when desired.

"He should watch closely all the work of assembling, and should see that proper methods are employed to insure connections being properly located and adjusted. After the work is assembled and before any riveting is done, he should see that all abutting surfaces are drawn tightly together, that the holes match well, and that they are properly reamed, so that there will be no shifting of the work by the use of drift pins.

"In reaming holes the reamer should be kept perpendicular to the face of the metal that is being reamed; and abutting members should be so tightly bolted together that no burr will be formed between them by the reamer. In the case of machined surfaces where full bearings are required, the Inspector should see that the work is drawn up tight, and that the full value of the bearing is obtained. Before any riveting is done, it is well to check up the work as much as possible.

"5. *Riveting.*

"The rivets should not be more than $^1/_{16}''$ less in diameter than the diameter of the finished holes; and they should be of the proper lengths. They should be properly heated, and driven before they are allowed to cool. When the metal to be riveted is thick, special care should be taken with the riveting. The head end of the rivet should be heated more than the plain end, so as to cause the head end to upset before the end on which the head is to be formed, and thus fill the hole completely. On account of the amount of cold metal all around the rivet, which causes the latter to cool rapidly, it should be driven as soon as it is put in place and before it has time to cool. The pressure should be kept on the rivet until it is sufficiently cold to take a set.

"The Inspector should see that the riveter is properly operated, and that power-driven rivets are used wherever possible. He should constantly test the rivets so as to see that they are tight. Where rivets have to be driven by hand, he should test all rivets carefully, and should see that the riveting is well done in all difficult places. During riveting he should see that the work is not being drawn out of shape, nor twisted, and that connections are not being shifted.

"Rivet heads must be well formed and in good alignment; and where work is exposed, special care must be taken to have the rivets make a good appearance in every respect.

"6. *Facing and Machining.*

"The Inspector should see that facing is done wherever called for. He should assure himself that the machine used for facing will give accurate results, and should check up the work, when it is to be faced, so as to see that it is laid out properly. In

cases where surfaces are faced on a bevel, the bed of the facer is the best place to check the accuracy of the work.

"Where built up sections are faced, all component parts should be securely riveted or bolted together, as near as possible to the finished surface. In other words, the facing tools should cut through all the component parts as though they were a solid piece of metal.

"7. *Checking Metal.*

"All through the shop inspection, the Inspector should have with him his note book on mill inspection, and should check up the heat numbers, in order to assure himself that the steel he tested is being used. In case he did not inspect the steel himself in the mill, a list of the heats tested and accepted will be supplied him by the inspector who attended to the mill work. He should also check up the different sections by calipering and measuring them.

"8. *Weighing.*

"When the work is finished in the shop it should be weighed, and the Inspector should check these weights.

"9. *Cleaning and Painting.*

"All steelwork must be well cleaned of scale, rust, dirt, and shop grease, and painted with the specified paint. The paint must be well rubbed in, and all cracks and open places must be filled. The Inspector must have quick methods of determining the character of the paint used, and must make what analyses he considers necessary to determine its quality. The knowledge of paints is a study in itself, and special information and instructions concerning the specified paint will be given to the Inspector.

"10. *Final Checking up and Measuring of Work.*

"The Inspector should make a final inspection of the work, and assure himself that all dimensions are correct, and that the work will go together without trouble. In case where it is very complicated, it should be assembled at the shop, the necessary reaming and chipping done, and the different members match-marked.

"Among other things specially to observe and check are: The distance from last hole to end of member, chipping of the countersunk rivets, smoothness of bearing surfaces where steelwork is to bear on masonry, and the proper finishing and smoothing up of slotted holes.

"11. *Shipping.*

"As material is shipped, it should be checked off on the plans; and the Inspector should see that it is forwarded in such a manner as not to delay the erection in the field. Often the omission to ship an important member will completely block the work of erection for a considerable time.

"12. *Conclusion.*

"Always have your work well in hand; be observant; and if you have any fault to find with the way the work is being done, speak of it to the right parties, and have the required remedy in the proper way.

"Be courteous but firm, and always mindful of your duty. Do not expect perfect work, but do everything in your power to obtain the best results and to make the work a credit to all concerned; and remember that it is better to be respected for conscientious work than to cater for friendships at the expense of your own reputation.

"Work with a view of increasing your own knowledge and gaining in expertness. Make notes of what you observe and of all experiences gained on each piece of work.

"Add to these instructions any points you think will strengthen them, for they are intended as a foundation for the attainment of the best results."

The following are Hildreth & Co.'s general and detailed instructions to their assistant inspectors:

"GENERAL INFORMATION TO INSPECTORS

"1. *Tape, etc.*

"You will be furnished with a standard steel tape and our special stamping hammer, for which you will be held responsible. You will supply yourself with light hammer for testing rivets, steel straight edge, calipers, rule, and other necessary tools.

"2. *Report Blanks.*

"You will be supplied with a full line of our blanks, and you should see that they are not allowed to run out.

"3. *Reports.*

"Progress reports must be made weekly, or according to special instructions. Monthly reports and check of contractor's estimates, as per special instructions, final reports as indicated later. Press or carbon copies of letters and carbon copies of reports should be kept. A diary of each day's inspection should be kept for purposes of weekly and final reports. All reports should be neatly made out with copying pencil so that we may make a press copy and forward original to our clients. Where more than one copy is required make extra carbon copies.

"INSPECTION OF MATERIAL

"1. *Honesty of Mill.*

"Must be constantly checked as regards stock used and methods of piling, or casting, blooming, rolling, identifying with melt numbers, preparing test pieces, weighing, etc. All test specimens must be known to represent material inspected.

"2. *Physical Tests.*

"When possible, should be made before surface inspection; must in all cases be conducted personally. Drifting and bending tests are as important as tensile tests. All such must be reported by outlining on regular form. Punching, forging, and other special tests, as per special instructions.

"3. *Chemical Tests.*

"Mill tests must be reported and accuracy frequently investigated. Where independent tests are to be made, samples must be taken personally.

"4. *Surface Examination.*

"Every piece must be examined for surface defects, section, and straightness as far as mill facilities permit, and if completely inspected and acceptable, identified by our special stamp, otherwise not stamped. Universal mill plates should receive special attention and, unless perfectly straight, must be tried with a 'line.' Do not allow variation of more than $\frac{1}{8}$ of an inch in 30 ft. Section should be checked with rule and calipers, and if there is any suspicion of light weight, pieces should be weighed. Lists of pieces accepted or rejected should be made on 'Material Represented' blanks. Such lists should be compared at the time with shipping clerk's list and later with invoices. You are to demand proper facilities for inspection during daylight; if such are not furnished, you will make the best inspection possible and report the facts.

"5. *Shipments.*

"Report all shipments as per blanks, and send us copies of shipping invoices. In the event of shipment without inspection, or of rejected material, advise us at once,

giving date and car number so that we may make proper arrangements for inspection on receipt at shops. On completion of each order return order sheets to us checked off showing that each piece has been accounted for by melt number.

"6. *General.*

"In the interest of clients and of the bridge shops, you should make special efforts to facilitate rolling and shipping, and should see that rolling for items for your orders is completed before rolls are changed and that other orders are not allowed preference. Give special attention to following up odd items in list, or arising from condemnation. Advise us promptly of any unreasonable delays.

"GENERAL INSTRUCTIONS TO SHOP INSPECTORS

"1. Check the shop drawings for clearances, and estimate the weights, when so instructed, in advance of manufacture, reporting results to us before shipment begins; see that every dimension which in any way affects the assembling of the work at the site is correct; that all clearances are ample and that the drawings which you are using have been approved.

"2. Prior to actual inspection, you should carefully compare your tape with the shop standard, note the differences, if any, at each even five feet, and thereafter make the proper allowances for all measurements.

"3. You are to keep in close communication with us, not only through report forms, but also should consult us frequently regarding the standing of shops, shop methods, and all important questions arising in connection with the work. Inasmuch as our inspection contemplates considerable of our personal supervision, you should advise as to the proper time to go over the work with you and later to see the work at its most important stages. This is particularly intended to apply to important riveted and skew spans, draw spans, and turntables.

"4. Whereas your authority does not extend over shop methods, good inspection requires the prevention rather than the mere discovery of defective workmanship, and it must be conducted with judgment to anticipate poor work. It is also your duty, second only to that to our clients, to save contractors all reasonable expense or delay; and you must conform to their right to prompt attention and your presence during working hours. In the interests of all parties concerned, it is necessary that you give the work constant supervision and conduct the inspection with foresight and tact.

"INSPECTION DURING MANUFACTURE

"You should read carefully all specifications as soon as received and make note of important requirements. Do not assume that all specifications are alike and that general shop methods are acceptable. You should keep a close watch on all details of manufacture, giving particular attention to the following points:

"1. You should begin work with the template and pattern shops, particularly on drawbridge, skew span, or lattice girder inspection, and should check templates and patterns as far as possible, and without fail witness all laying out of full sized templates.

"2. Careful surface inspection of all material during handling, punching, and assembling to discover defects not found at the mills.

"3. Watch straightness of material, particularly heavy angles after punching.

"4. Supervise all punching closely; give special attention to accuracy of punching and use of proper dies and punches; have special care for cracks developed by punching; and watch for evidence of burnt or over-heated steel, condemning such rigidly. It is only at punching that slotted holes can be prevented. Punching must be accurate or the material must be rejected.

"5. Care at assembling: Matching of holes and use of sufficient number of bolts; proper reaming; straightness of assembled members; removal of all burrs; bearing of

stiffeners; watch for errors at this stage of shop work from not following plans, particularly as to 'rights' and 'lefts' and proper section, errors discovered at this stage of manufacture being more easily corrected than later.

"6. Riveting at good pressure and with properly heated rivets. Rivets should in no cases be much hotter at points than at heads, as is frequently the case. Inspect rivets at the riveter whenever possible; always on first part of work and as frequently as possible during progress; the disciplinary effect in improving the riveting being much greater than if inspected in the yard. See that defective rivets are replaced and not squeezed up cold or caulked.

"FINISHED MEMBERS

"An inspection of finished members should be made as soon as they leave the last tool and before paint is applied; the following points should receive your special attention:

"1. Members to be looked over for defective material or defects caused in manufacture (split plates, ends of lattice or angle bars split), also for bearing of stiffeners, straightness, and wind.

"2. Rivets to be hammer-tested and examined for split or wasted heads and caulking.

"3. Measure diameter of all pin holes; whether in axis of member or as called for and at right angles to axis.

"4. Diameter and length of pins and rollers,—examine for flaws.

"5. All length measurements, centre to centre, faced end to faced end, and out to out. Depths of chords and girders.

"6. Main section of all members, check carefully to be sure that material is of correct section and located as required.

"7. All clearance measurements where pieces are likely to interfere in the field, particularly inside and outside of chord sections and posts, thickness of heads of eye-bars, etc., cuts of flanges of chords and posts, depth of stringers and floor-beams, etc.

"8. Whether faced surfaces are at right angles to axis of member, or are inclined at the proper angle, if they are beveled. Floor connections not faced off too much, giving scant section.

"9. Number and position of countersunk and flat head rivets.

"10. Number, size, spacing, and location of all bolt and field rivet holes, pin holes, or other connections.

"11. Pairing of pieces. This is very important through the ease and frequency with which mistakes in pairing are made and overlooked.

"12. Checking of all corresponding field connections (*e. g.*, floor system); get a special template from the shop for this purpose when desirable on account of a large number of similar connections.

"13. Eye-bars should receive particular attention. All eye-bars of a kind should be of same length, back to back of pin holes, although each kind of bar may vary from length called for by not more than $^1/_{32}''$. In addition to length and pin-hole measurements, heads and bodies should be calipered and measured; and bars, particularly heads, should be examined with the utmost care for flaws and piping. No flaws whatever in heads should be passed.

"14. Where required, compression chords should be lined up with splice plates in position; turntables of drawbridges, riveted trusses, skew spans, skew portals, or other important or difficult work should be assembled. Connections of all work assembled should be match-marked.

"15. Marking of pieces should be adequate and should be checked.

"16. Painting to be thoroughly done before fitting up and on finished work. See that quality of paint is as specified. See that all material is free from scale or rust, and if not, that it be thoroughly cleaned and dry.

"17. Weighing should be known to be correct, and shipment should be watched to see that pieces not accepted are not shipped; also that loading is properly done to prevent injury during transportation. Compare actual and estimated weights before shipments leave the works and determine the reason for any difference. Pieces of different kinds must be weighed separately.

"18. Immediately shipments are made report to us. Keep memorandum of pieces and weights. When final shipment is made compare your total for actual weight with that of the shop to see that you have all invoices and advise us, sending invoices and your estimate of weights and final report.

"SHOP INSPECTORS' FINAL REPORT

Plans

"*Description:* As soon as plans are received report a description of work, type of structure, pin-connected, riveted or plate girder, deck, half through or through, single or double track (if highway, width), length c. to c. and clear; note if skewed.

Material

"As soon as plans are received we must have a list of all members, arranged in same order as estimated weights. This can be taken from the plans or generally had from the drawing room for the asking.

Weights

"*As soon as plans of bridges are received* weights must be estimated and shown for different members, grouped into:

"(1) Trusses, (2) Girders, (3) Floor, (4) Wind Bracing, (5) Pier Members, (6) Field Rivets and Miscellaneous, (7) Draw Machinery (need not be estimated unless under special instructions). This can be done when list of material is made out, and should follow same order.

"Scale weights must be compared with estimated weights, and weighing must be done accurately, so that such comparison can be made. If several pieces are to be weighed together, the total must be reasonably proportioned according to estimated weights and must so check. This must not be permitted for important pieces. At completion of job, compare your total weight with that of the shop and be sure you have all invoices.

"*Answer Every Question Below Within One Day of Final Shipment. When Desirable State Fully in Detail*

"1. What errors did you find in plans? How corrected?

"2. Did you examine all material and compare with detail plans for size and section during shop inspection; did you condemn any and why?

"3. Were any errors due to incorrect templates? What and how corrected?

"4. Was material straight or straightened before and after punching?

"5. Did any material crack in manufacture, and was it replaced?

"6. How accurate was punching? Did you do anything to watch and improve punching?

"7. What was the size of dies and punches? Full size or sub-punched?

"8. Were assembled members straight and held tight with sufficient bolts? Did holes match reasonably?

"9. Was reaming done? With what kind of tool? How much metal was removed? Were all the holes cleaned out? Were burrs removed? Were finished holes slotted, and to what extent?

"10. Did you compare the work with plans at assembling, and did you find any errors?

"11. How many rivets were replaced? Where were they located, and what was the matter with them?

"12. Were any errors found in machine work? (Pin holes, faced ends, etc.)

"13. Were any field connections reamed to iron template, and what?

"14. Were any field connections assembled and reamed? Were they match-marked? How?

"15. If a draw-span: Were centre and machinery assembled? How much of it? How did you examine it? What did you find? (State this in detail.) Were assembled parts match-marked?

"16. What kind of paint was used? How many coats were used at assembling and finally? Was the surface clean and dry? How was cleaning done? Was painting thorough? Was paint dry before shipment? Was the finish good or streaky?

"17. Did you make final examinations? Was every section of material as called for and correctly located? Were members straight? Was general appearance neat and workmanlike?

"18. Were scale weights correct? Did you personally witness weighing?

"19. How were loading and packing done? Were bolts and rivets boxed? Were plates and fillers bundled?

"20. Give date when shop work began; also date when final shipment was made."

The following are extracts from a letter of Messrs. Robert W. Hunt & Co., dated May 3, 1915:

"We have carefully read over Chapter 21 of *De Pontibus* on 'Inspection of Materials and Workmanship,' and believe that your standard instructions to the Inspecting Bureau and to the Inspectors employed to look after work at mills and shops pretty thoroughly cover the essential features to be looked after.

"It is, of course, assumed that all inspectors employed on work of this character possess sufficient experience, knowledge, and common sense, to see that the requirements of the specifications and plans are complied with, without going into minute detailed instructions. However, in reading over these paragraphs in *De Pontibus*, a number of important items, which are not included therein, suggest themselves, and which are very apt to be overlooked by some inspectors, as follows:

"*Mill Inspectors.*

"Familiarize yourself with conditions at the shop and endeavor to expedite the work by seeing that the material is shipped from the mill in the order in which it is needed for fabrication.

"Supervise the selection and stamping of test specimens and verify the heat numbers whenever practicable. Secure records of mill analysis promptly and check against results of physical tests before accepting the material.

"Examine all material for surface defects, evidence of excessive gagging, or injury due to cold straightening; and look out for buckles in wide plates and the alignment of universal plates, check the material for section and weight, and do not leave these important details to the loader or shipping clerk.

"Supervise the making of tensile, bending, and drifting tests; check the measurements of the specimens, and see that the testing machine is properly manipulated and that the specified speed of pulling is not exceeded. Check the readings on the machine, and note the behavior of the metal under test and the character of the fracture. Do not be satisfied simply to accept the mill's record of tests.

"*Shop Inspectors.*

"Acquire a full knowledge of the specifications and of the conditions of the contract, particularly as to time of delivery, customer's actual need of the work, desired order of shipment, and other special features to which particular attention should be paid.

"Co-operate with the manufacturers, and endeavor to cultivate pleasant relations with the superintendent, foreman, and workmen by displaying fairness, decisiveness, and good sense. Try to interest them in the successful carrying on and completion of the work.

"Attend constantly to the work, making inspection during the progress of fabrication, so as not to interfere unnecessarily with the routine operations of the shop, striving to keep up with the output, so that errors or defects may be caught and corrected before the work leaves the shop, thereby avoiding unnecessary handling and delay.

"Study the field connections, paying particular attention to clearances, make notes on drawings, and report promptly any interference which may occur.

"See that the correct sizes of punches and dies are used, particularly on sub-punched work, so that the proper amount of metal is left to be removed by reaming.

"See that all reamed holes are true, cylindrical, and not oblong, that burrs are completely removed from the holes, and that no chips or drillings are allowed to remain between the contact parts.

"See that plenty of bolts are used in assembling so as to draw the material together tight and that sufficient pressure of air is maintained constantly for the riveters properly to upset the material, completely filling the holes and producing tight rivets. See that the rivet heads are of uniform size and well lined up.

"Make sure that reaming-templets are properly set and secured in position.

"See that all splices are properly fitted, and that milled surfaces to transmit bearing are in close contact during reaming and riveting.

"See that proper camber blocking is used in assembling girders and trusses, so as to obtain the desired amount of camber before reaming.

"Make sure that all spliced members are plainly match-marked, and secure match-marking diagram for all work which has been assembled and reamed.

"Check carefully sizes of pins and pin holes, and be sure that the latter are accurately bored at right angles to the axis of the member.

"Look out for twists, bends, and kinks in the finished members, and make sure that when leaving the shop they are in proper condition.

"Verify the erection marks and see that they are legible and put on in some conspicuous place.

"See that the weights of all main members, especially girders and other heavy sections, are plainly marked on the piece for the erector's benefit.

"See that all large members, particularly girders and chord sections, are loaded so as to be headed in the right direction on arrival at the site.

"Make sure that all loose pieces are bolted in place for shipment, as shown on drawings, and that other small parts are properly boxed or otherwise secured against loss in transit.

"See that material is loaded in accordance with instructions and shipped in correct order for erection.

"Examine cars on which material is loaded and see that they are in good order before being sent out.

"In case of any dispute between inspectors and the manufacturer, or any deviations from the plans and specifications, the work in question should be held up and the matter immediately reported to the Engineers.

"All drawing room errors, as well as shop errors which affect field connections, should also be recorded and reported immediately.

"*General.*

"Inspection Bureau should employ only first-class men for inspectors, who have had experience and training in the particular line of work on which they are to be used, and should not borrow or hire the bridge company's or mill's employees to help out their inspectors when assistance is needed."

Colby & Christie's little handbook, by Schneider and Colby, entitled "Inspection of Structural Steel Work," contains many pointers of great value to inspectors, but most of its clauses are really in the form of specifications to govern the manufacture of the metal in the shops; and in form, at least, they apply more directly to the contractor than to the inspector. However, they are of such excellence that most of them which deal with topics not hereinbefore fully treated are reproduced as follows:

"*Testing Machine.*—The Inspector should make sure that the testing machines are properly handled, and that the specified speed of pulling (usually 2 inches per minute until yield point is determined and thereafter increased to 6 inches per minute) is adhered to.

"*Surface Inspection and Verification of Dimensions.*—When practicable all material should be inspected at mills before shipment; such inspection to cover surface finish and dimensions. Should the conditions at mills be such as to prevent inspection before shipment, acceptance should be subject to inspection at point of destination, with the understanding that all material defective as regards dimensions, finish, or surface imperfections shall be subject to rejection and replacement at the maker's expense.

"*Receiving Material.*—The Inspector should be on hand whenever material is unloaded from the cars, and should check the material with the shipping invoice, so that only such material will be received as has been tested and accepted by the inspector at the mill.

"*Protection of Material.*—Material received from mills and held at shops awaiting fabrication should be protected from rust; oiling of the tops, sides, and ends of piles will generally be sufficient.

"*Straightening.*—Although 'merchantably straight' when shipped from mills, a majority of plates, and in some cases angles and shapes, require further straightening before being punched. Such straightening should be done in rolls and not by sledges or hammers; buckles should be removed by adjusting the rolls or placing narrow strips on edges of plates, thus drawing or stretching the outer edges when passing through rolls. Blows struck on buckled surfaces will increase the defect.

"*Annealing.*—Where a portion only of a plate, angle, or shape is heated for the purpose of bending or forging, a strict compliance with the specifications requires that the entire piece be annealed. This requirement is at times disregarded, as in the case of rounded top corners of through plate girders where, owing to the fact that metal at this point is subject to little stress, annealing may be waived without risk. Such plates and angles should, however, be bent to a true curve and be free from short bends or waves, so that the entire face of angles will bear evenly on the plate.

"*Annealing of Long Angles.*—In girders which have a greater depth at the centre than at the ends, such as main girders of turntables, long floor-beams, etc., the flange angles of the bottom chord are generally given two decided bends, requiring partial heating and, to some extent, forging. As such angles usually occur in girders which receive severe live-load stresses and impact, they should be annealed, as called for in all specifications. However, owing to the lack of facilities for annealing in most bridge shops, such annealing is generally omitted. (The proper course for the Inspector to pursue in cases of this kind is not to accept the work on his own responsibility, but to take the matter up with his employer and the shop manager, and let his employer decide whether it will be safe to omit the annealing, as an excess of strength may have been provided in the design to make up for the possible defects in the unannealed angles.)

"*Straightening After Punching.*—Material which has curved during the process of punching should be re-straightened.

"*Bolting Sub-Punched and Reamed Work.*—Sub-punched and reamed work should,

when assembled, be so thoroughly bolted as to ensure all contact surfaces lying flat and close to avoid the accumulation of reamer chips between various parts. In work drilled from the solid the various parts should be held in place by occasional small diameter bolts and by a sufficient number of clamps to bring all faces in close contact while being drilled. (High speed steel has made it possible to ream or drill without the use of lubricants, except for an occasional oiling of the drill to prevent sticking or clogging of holes.)

"*Bolting Members Against Distortion During Driving.*—When the various parts forming a member have been assembled, the entire member, whether chord, post, column, or girder, should be free from twist, wind, or bend, and should be thoroughly bolted to ensure against twist or change of form prior to or during riveting.

"*Injury to Material in Handling.*—In handling heavy members, care should be taken that edges of plates or angles are not scored or bent by chains or by falling on skid rails. (The use of blocking will prevent this.)

"*Driving Rivets in Long Compression Members.*—In riveting members, particularly long compression members, it is well to drive at different points instead of driving one continuous line. A twist or curve can be avoided by driving a portion of rivets in each flange and returning over the work to drive rivets in omitted holes and those from which assembling bolts have been removed.

"*Countersunk Rivets.*—In driving countersunk rivets the desired length of rivet is one that will completely fill the countersink without excess. This being difficult, the excess should be as small as possible in order to avoid chipping, which is liable to loosen rivets, particularly in thin material.

"*Driving Rivets.*—All rivets are intended and expected to be tight, to have full and symmetrical heads and to be in true alignment. Loose rivets can generally be avoided if material is carefully straightened and thoroughly bolted in assembling, if the proper lengths of rivets are used, and if the machines employed are of sufficient power. Where the above precautions have been observed the number of loose rivets will be found to be small, but when these precautions have been neglected a larger number of loose rivets is likely to be found, and, therefore, special care should be exercised in examining rivets.

"*Testing of Rivets.*—The proper testing of rivets requires intelligence and judgment. Specifications call for all rivets to be tight, and good practice requires that there should be no loose rivets in any part of a structure. However, as the tightness of rivets cannot be measured with instruments of precision, but can only be judged by observation, depending upon the keenness of the Inspector's ear to distinguish the sound or his ability to feel the vibrations when the rivets are struck by a hammer, these observations, like others depending upon the testimony of the senses, are not infallible, and rivets may be pronounced as tight by one inspector and as doubtful by another. It is, therefore, of the greatest importance that the testing of rivets should not be done in a perfunctory manner, but that intelligence and judgment should be exercised on the part of the Inspector as to the functions which the rivets have to perform.

"*Important Rivets.*—In cases where the whole strength of a member or a connection depends upon the resistance of the rivets, the utmost care should be exercised in testing, and only such rivets allowed as are considered absolutely tight. Rivets at the ends of plate girders, those connecting reinforcing plates to main members at pin connections, and those in riveted connections of either tension or compression members where the strength of the connection depends solely upon the value of the rivets and not on the bearing value of the abutting surfaces, may be mentioned as rivets which should be absolutely tight. In rivets which receive no calculated stresses, but the function of which is simply to clamp the material together (such as stitch rivets), or to keep the members in alignment (such as rivets in lattice bars or tie plates of secondary members), absolute tightness is not imperative.

"*Alignment of Rivets.*—The shape and alignment of original heads of driven rivets

should give little trouble, but some allowance should be made in this respect as regards the driven heads, as the flow of metal while upsetting is not confined to any given direction, and a slight deviation from a straight line or in the shape of heads can be expected.

"*Replacing Loose Rivets.*—The advisability of replacing loose rivets will depend on their location and the likelihood of securing better results by cutting them out and replacing without serious injury to the material or adjacent rivets. The motive for removing loose rivets would be the improvement of the work and not the imposing of a penalty on the riveter.

"Where a number of rivets in close proximity are loose, they should be removed along with rivets that may be loosened by reason of such removal, and, after clamping or bolting the work firmly together, the entire lot should be redriven. Rivets to be removed should, preferably, be drilled out instead of being backed out with a punch, especially where they pass through several thicknesses of metal.

"*Milling to Length or Bearing.*—The milling to length or bearing is a matter deserving attention. As far as possible the pieces to be milled should be supported on a temporary bearing strip of metal, part of which is milled away during the operation. Where this is not practicable, the cut taken should be light to avoid the breaking away or tearing of metal on the under or last side of cut. Cutters having broken cutting edges productive of scores or scratches should be removed and replaced, and the speed of feed should be slow in order to produce a smooth and even finished surface.

"*Milling of Ends of Stringers.*—In milling the ends of stringers or similar members to length, where connection angles project and constitute the length over all, care should be taken to have such angles square and flush with each other before being milled, otherwise the thickness of such angles will be reduced unevenly during the operation of milling, and in places to less than the thickness required.

"*Chamfering for Fillets*—Chamfering of ends of stiffener angles should conform to fillet or flange angles to which they are to be fitted and not be simply rough ground or sheared to provide clearance. Chamfering of plates used for reinforcing webs of beams or channels forming shoes or bolsters should be accurately done by planing with a tool ground to conform to the fillet of the beam or channel to which they are to connect.

"*Planing of Flanges of I-Beams and Channels.*—The faces of flanges of beams or channels in foundation grillages should be planed to a right angle with centre of web (except in cases where they are imbedded and covered with concrete). Flanges of these shapes generally come from rolls "out of square" with webs, and planing is essential when used as bearings of columns or end shoes.

"*Buckles in Web Plates.*—Web plates of girders should be free from buckles, but defects of this kind when not discovered until riveting has been completed may be allowed to pass, if the extent of buckle does not exceed $\frac{1}{2}''$ in $60''$. (This is an old rule, and since the introduction of effective straightening machines is seldom resorted to.)

"*Base or Cap Plates of Columns.*—Base or cap plates of columns, if not planed, should be carefully straightened so as to ensure a bearing of the entire section of shaft of column; and such base or cap plates and bearing plates at ends of girders or stringers should be examined for straightness after riveting, and any curving or deviation from a true flat surface corrected by restraightening.

"*Defects Developed in Material During Manufacture.*—Piping or other interior or surface defects, blisters, sand spots, etc., occasionally develop during the various processes of manufacture; and material containing such defects should, under ordinary conditions, be rejected and replaced. The location of the defect, its extent, the necessity for immediate completion, and the consequence of delay should, however, be taken into consideration; as under favorable conditions it may be possible to make use of plate or angle reinforcement, thereby safeguarding the strength of the member without detracting from its appearance.

"*Bolts for Permanent Connections.*—Bolts to be used in permanent drilled or reamed

connections should have a driving fit, and be neatly turned if so specified, but whether turned or rough, the grip length of such bolts should be free of threads and provided with washers to permit of their being drawn tight. The thread projecting through nut should be checked or burred to prevent loosening.

"*Castings.*—The castings should be examined carefully for blow-holes, shrinkage cracks, and other imperfections, but discrimination should be made between such defects as are unimportant and those which render the castings unfit for use. They should also be checked as to size and dimensions. For steel castings it is essential that the Inspector should ascertain that they have been properly annealed. This is generally indicated by their color, which should be blue after leaving the annealing furnace. If minor defects should be discovered in steel castings which are otherwise acceptable, the correction of such minor defects by electric or gas welding is permissible.

"*Reaming Field Connections to Templates.*—The reaming of field connections, such as those of floor-beams to posts and stringers to floor-beams, should be done by metal templates. These templates should be checked with the drawings before reaming is begun. For this purpose the drawings of posts as well as floor-beams should be used for floor-beam to post connections, and for stringer to floor-beam connections the drawings for both stringers and floor-beams should be used.

"*Checking Connecting Angles at Ends of Floor-beams and Stringers.*—Where connecting angles at ends of floor-beams or stringers are not reversible, care should be taken to see that angles are correctly placed, giving the proper starting space from seat angle to first hole. Stringers are frequently alike top and bottom, with the exception of holes for lateral connections or floor bolts; and it is possible, and sometimes happens, that end connection angles are reversed and riveted with top end toward bottom side of member.

"*Assembling and Reaming Riveted Trusses.*—When riveted trusses are assembled complete with all truss members and connections in place, such assembling is done with trusses by lying flat and not in a vertical position. It is then necessary, in order to avoid the turning of entire truss, to use long shanked reamers capable of reaming holes on both sides of chord without changing position of truss.

"*Camber in Riveted Trusses.*—When trusses are assembled complete, the lengths of the web members should be checked to make sure that they conform to the desired camber; but, before reaming, this camber should be checked, as it may be adjusted to some extent by drifting the sub-punched holes, after which all members should be firmly bolted to hold bearing joints in close contact. Fillers and splice plates which are to be shipped in place, without removal after reaming, should first be given a coat of paint the same as other surfaces in contact, otherwise they will, in all probability, be riveted in place at site without having been painted.

"*Reaming Field Connections in Riveted Trusses to Templates.*—When trusses are too large to permit of complete assembling, it becomes necessary to use templates for reaming the holes of each connection (other than chord or end post splices, which should be reamed while joints are abutting and in line.) Such templates should be provided with centre lines and marks indicating position as regards distance from centre of holes in member being reamed to centre line of member to which it is to connect. They should be either of metal or of seasoned wood with metal thimbles. (Metal templates are to be preferred if they are to be used on duplicate parts).

"*Checking Sizes of Pins.*—In pins of smaller sizes, say up to 8″, the diameters can properly be checked by ring or snap gauge furnished by the shop, but on larger sizes the circumference should be measured with a tape in addition to being measured by calipers.

"*Checking Pin Holes.*—Pin holes of moderate size can be checked by plug gauges usually to be found at shops, but when such gauges are not available, or on large diameter pin holes, the diameter should be carefully checked with micrometer gauges. As the clearance for pins seldom exceeds $^1/_{32}$″, it is important to ascertain that both

pins and pin holes are correct as to diameter. The accuracy of fit of pins of large diameter can be best assured by trying them in place. It is also advisable to ship them in place wherever practicable, as the expense of boxing is thus avoided.

"*Checking Rollers.*—Roller nests, particularly those for large spans, should be checked by assembling roller bearing plates, roller nests, and upper shoes together, thereby ascertaining the uniformity of the diameters of the rollers and the extent of horizontal motion existing where this motion is controlled by stops on shoe bases.

"*Examining Eye-bars.*—Eye-bars should, wherever practicable, be piled in lots of from four to eight bars (depending on the thickness) and pins passed through pin holes to insure proper clearance of pins and uniformity and correctness of length of bars c. to c. or b. to b. of pin holes. Bars should also be examined singly as to gauge of pin holes and freedom from surface defects. The diameter of heads of bars should be checked to avoid fouling flanges or cover plates of end posts or chords and chipped if necessary to provide the required clearance.

"*Adjustable Bars.*—Adjustable bars connected by turnbuckles should, when coupled together, measure within $\frac{1}{2}''$ of the length shown on shop print. Threads of upset ends should be close fitting and capable of entering the turnbuckle to the full length of thread by the use of a wrench having a leverage of four feet. With loose fitting threads, turnbuckles, unless provided with jam nuts, are liable to work loose in service.

"Machinery Parts of Movable Bridges

"The inspection of machinery parts of movable bridges requires special care, and such work should be entrusted to experienced men only.

"The Inspector should carefully study the design of all the details and discriminate between those dimensions which must be exact and those in which slight variations are permissible.

"*Finish.*—All workmanship and finish should be equal to that of the best practice in modern machine shops. As the parts of the operating machinery of movable bridges are generally exposed to the weather, the finish should be confined to the bearing, rotating, and sliding surfaces, and wherever it is required to secure precise and accurate fits and dimensions.

"*Fixed Parts of Machinery.*—As it is of the greatest importance to have all fixed parts of the machinery of movable bridges properly fastened so that they may not become loose during the operation of the bridge, special care should be exercised to assure proper fastening of such parts as bearings for shafts or journals, hubs of wheels, pulleys, couplings, collars, and similar parts to the shafts or axles to which they are attached. Therefore all bolts which are used to hold such parts in place should have a tight fit in their holes, unless other precautions are provided for in the design, and all nuts should have tight-fitting threads.

"*Hubs.*—All hubs of wheels, pulleys, couplings, etc., should, besides having a close fit on the shaft or axle to which they are attached, be provided with properly fitting keys. Special attention should be paid to the fitting of such keys. If a hub performs the function of a collar, the end next to the bearing should be faced. Holes in hubs of toothed gear wheels should be bored concentric with pitch circle.

"*Pivots.*—The Inspector should satisfy himself that the proper material as called for in the specifications is used for discs, friction rollers, or balls used in pivots. He should see that they are accurately turned and finished to gauge and oil tempered, if made of tool steel, and that after hardening they are accurately ground to their final finish. Steel and phosphor-bronze discs should have their sliding surfaces finished to a high polish.

"*Worm Wheels.*—Threads on worms should be cut, and the teeth of worm wheels should fit the worm accurately.

"*Lubrication.*—The Inspector should see that provision is made for proper lubri-

cation of all rotating and sliding surfaces and that oil cups are provided wherever necessary.

"*Assembling Turntable Centres.*—Turntable centres for swing bridges, whether of conical roller or disc type, should be assembled and made to revolve for at least six hours to develop existence of soft or weak spots in roller or bearing surfaces. Suitable oiling holes and grooves should be provided, whether specified or not, if the necessity for their presence is apparent.

"*Assembling Turntables for Swing Bridges.*—Track, rack, rollers, and centres of turntables for swing bridges, together with circular, radial, and distributing girders and other parts belonging to and connecting to the turntable, should be completely assembled. After assembling, all parts of the operating mechanism, with their connections and attachments, should, as far as possible, be tried in place.

"*Proprietary Paints.*—Where proprietary paints are called for in the specifications, the inspector should see that the original packages from which such paints are taken bear the brand, trademark, or other identification mark of the maker specified. No adulteration or dilution of such paints should be permitted, other than that intended and recommended by the manufacturer.

"*Red Oxide of Lead Paint.*—Where 'Red Oxide of Lead' is specified as the pigment and linseed oil as the vehicle, it is essential that both lead and oil be analyzed at least so far as to establish that the quality of such materials is as claimed by the makers whose names appear on the original packages.

"Red lead or other paints containing heavy pigments are difficult to apply evenly, owing to the tendency of the pigments to precipitate or settle, producing streaks and accumulations of excess pigment and separation from the oil or vehicle. This may be prevented by the use of lamp black if permitted by the specifications. If this is not permissible, the use of a small amount (say 1 gill per gallon) of Japan drier will cause an immediate partial hardening, thus preventing this objectionable precipitation and streaking.

"*Records for Erection.*—A record should be kept of all matters affecting the erection at site, as, for instance, the changing of rivets from shop to field-driven, the special marking of parts made non-interchangeable by reason of corrected shop errors, the possibility of close-fitting connections, and the match-marking of fitted joints, a copy of which record should be forwarded to the erector."

Some two decades ago the author had made for him by one of his inspectors a rather interesting series of tests to determine the average accuracy of sub-punched rivet-holes. These tests were made after the metal was assembled for reaming by inserting rods of various diameters in the assembled holes. From the results thereof the author prepared the following clause for his specifications; and he has used it ever since. It is Clause No. 83 of Chapter LXXIX.

"All punched work shall be so accurately done that, after the various component pieces are assembled and before the reaming is commenced, forty (40) per cent of the holes can be entered easily by a rod of one-sixteenth ($^1/_{16}$) of an inch less diameter than that of the punched holes, eighty (80) per cent by a rod of a diameter one-eighth ($\frac{1}{8}$) of an inch less than same, and one hundred (100) per cent by a rod of a diameter one-quarter ($\frac{1}{4}$) of an inch less than same. Any shopwork not coming up to this requirement will be subject to rejection by the Inspector."

It will be noticed that this specification does not reject absolutely all work that does not come up to its exact requirements, the Inspector being

allowed some latitude in distinguishing between simple and complicated shopwork, important and unimportant connections, and the assembling of few and of numerous component pieces.

If the Association of Inspectors previously suggested were established, it could do good work for the engineering profession by laying out a series of tests of full-sized members and details of bridges and other structural metalwork to be made from time to time as a portion of the inspection for large contracts. This would need the assistance of the consulting engineers, who, in preparing their specifications, should include, as a part of the work of the manufacturers, the making, under the supervision of the inspectors, of certain tests of full size parts, it being understood at the outset that the results of such tests shall be of direct value to the accomplishment of the work covered by the specifications. The author has for many years been endeavoring in this way to obtain some much-needed information concerning the strength of both main members and details of bridges and elevated railroads; but his attempts to have the tests made have not always proved successful.

It occasionally occurs in a bridge engineer's practice that he is absolutely forced into using stock material for a structure. Such a method of manufacturing structural steelwork is always highly objectionable (although not so serious a matter today as it used to be, because the general manufacture of rolled metal has become materially improved and thoroughly systematized); nevertheless there are occasions when a steel bridge has to be built upon the spur of the moment in order to meet some emergency which will not permit of the metal being rolled specially. In such cases the engineer has to make the best of a bad business; and, if he is wise, he will be liberal in proportioning his sections (unless the plans also be taken from stock); and he should give the metal that he uses as thorough an investigation as possible. The method adopted by Messrs. Hildreth & Co. is given as follows:

POLICY FOR ACCEPTANCE OR CONSIDERATION OF STOCK MATERIAL

"The following method of dealing with the question of use of stock material at Fabrication Shops must be followed closely:

"(1) Where permission for the use of stock material is given by our client and it is made plain to us that the question of tests or the identifying of metal is waived, we are called upon only to inspect the material for size, section, and surface.

"(2) Where permission for the use of stock material is given by client under the condition that its quality must be identified by us, we must make the attempt to make such identifications; first, by requesting the shop to furnish us with record tests giving heat numbers; and then, if these are available, a further endeavor must be made to identify the heat numbers on the material. This will generally be found to be impracticable, as few heat numbers are retained on the material cut into commercial lengths and as generally found in the shop stock supply. If the heat numbers cannot be found on the material, the identification is not complete. This must be made plain to the client, and the records must be reported only for what they are worth.

"(3) Where no record tests are available, or where the client is not satisfied with the records of tests without identification of heat numbers, the only other way of determining

the quality of the material is to have a test piece cut from every piece of material to be used, as all may be from different heats. This is impracticable on account of the loss of time, the expense involved, and the fact that the cutting of pieces of sufficient length for tensile tests would spoil the commercial lengths of the material. In lieu of the complete testing, one or several test pieces to represent the whole lot of material may be suggested by the steel company or considered by the client. In this case we can follow out the idea; but it must be made plain that this does not represent the quality of any of the material, except the actual piece tested, when the heat numbers cannot be found. In being a party to any of this testing of stock material, it must be made plain by us what is accomplished, that there is no complete identification of the quality of the material and that we accept responsibility only accordingly.

"It must be clearly understood by the contractor or steel company that the preparation of test pieces from stock and the arrangements for testing of same must be at their expense; and we should not proceed until it is on record that this expense is to be assumed and accepted by somebody.

"(4) In the absence of any identification by record test or by the preparation of test pieces cut from the material, we can get a general idea of the quality by making bending tests on crop ends as the pieces are cut for finished lengths, so as to insure against the employment of brittle material.

"(5) In considering the use of stock material under any method of testing, it should be carefully inspected by the shop inspector for surface defects; and any pieces that show signs of pitting from rust or that cannot be cleaned in a reasonably good manner for painting should be rejected.

"The above applies to main sections of material under stress. Materials such as fillers, connection angles, and other small pieces can generally be permitted to be taken from stock without identification of quality by tests, if they are in good condition as regards surface."

Hildreth & Co. have evolved and patented a deformation test which ought to prove valuable. The following is a description of it as furnished to the author by the courtesy of that company.

"THE HILDRETH DEFORMATION TEST

"(Patented)

"The established method of testing structural steel consists of the choice of portions of the finished material from which test pieces are prepared to represent each original furnace melt. The number of test pieces is generally one for bending and one for tension, and they may represent from fifty to ninety tons of metal. Occasionally additional pieces are tested by punching, drifting, forging, or, in the case of angles, by opening out or closing down. This method of testing has been in effect practically since the commercial use of steel, and originally was valuable in showing the quality of the furnace charge. A number of years ago the condemnation of furnace melts was frequent. At the present time there has ceased to be any wide variation in the quality of steel. It is practically unknown that an entire furnace melt is condemned, except because it may be of one grade of steel, whereas another has been specified. In short, the manufacture of steel in a furnace has been mastered and is now uniform in character.

"As the steel industry has developed, greater attention has been given to the economics of manufacture and to the increase of tonnage, with a result that to-day the objectionable defects in steel arise, primarily, from the segregation of elements and from piping, which affect the finished product because of insufficient crop of the ingots, and, secondly, from defects which occur because of too rapid breaking down of the ingot, and from seams caused by metal over-lapping in rolling.

"It is not improbable that one hundred furnace melts of steel may be tested by

recognized practice and found acceptable, whereas out of every melt there may be a percentage of finished shapes and plates, which are brittle from segregated phosphorus or carbon or are defective from piping or seams. These defects are rarely evident on the surface; and the problem is to prevent their getting into the finished work.

"The following method of testing is conceived to determine the quality of every piece of metal used in a structure at a point closely adjacent to where the section is diminished by connecting rivet holes and where failure is likely to occur in connections. It is distinctly a practical test and conducted at the shop without additional handling and at an insignificant cost. It has the special advantage of branding every piece

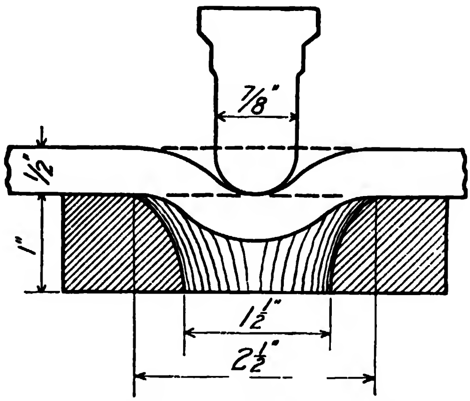


FIG. 59a. Hildreth & Co.'s Deformation Testing Apparatus.

of metal tested and of not requiring the presence of an inspector or expert. It is particularly applicable to stock material where there are no records of the original furnace melt numbers and when it is impossible to cut test pieces of any size from the material. It is not claimed that such tests determine the theoretical tensile or other strength of the metal, but that they do determine general or local brittleness and demonstrate the safe and workable character of the material.

"An old, worn, or broken $\frac{7}{8}''$ punch is turned down to a hemispherical end. A piece of 1" plate is turned out to a die $1\frac{1}{2}''$ at bottom and $2\frac{1}{2}''$ at top, as per sketch; the length of the punch being short is adjusted by washers or pieces of steel between it and the punching machine, so arranged that the punch itself will travel below the surface of the metal to be tested a distance equal to the thickness of the metal. The die is simply centered on the base block of the punching machine.

"The test consists of deforming the metal at a point between or adjacent to rivet holes for a diameter of about 2 inches. This deformity is carried to the extent of $\frac{1}{2}''$ for metal up to $\frac{1}{2}''$ thick; for metal over $\frac{1}{2}''$ thick, the distance should equal the thickness of the metal. This gives an excellent practical test of the working quality of the metal and a combined bending, punching and drifting test closely similar to tests of such character. Any brittleness will show by cracks on the convex surface. Tests can be conducted in the shop as the material is being punched and handled at an expense of less than 3 cents per test. It is necessary that the 'Layer-out' shall indicate to the 'Puncher' the point for test so that it will not interfere with the riveting of any work."

Fig. 59a illustrates the testing apparatus.

As for the proper price to pay for first-class inspection, the author would state that some twenty years ago he submitted to several of the

principal inspecting bureaus a draft of instructions to inspectors at mills and shops, similar to those incorporated in this chapter, with a request that they tender upon inspecting for him, according to said instructions, a large order of structural steel; and that the bids received varied from one dollar to one dollar and twenty-five cents per ton of two thousand pounds. Subsequent experience has proved to the author that such inspection as he then called for is worth fully one dollar per ton for large orders and a trifle more for smaller ones; although it is very seldom that such a price is paid in this country for inspection.

Today the price of the best inspection at mills and shops runs from sixty (60) to seventy-five (75) cents per ton; and it is evident that one cannot expect to obtain dollar inspection for seventy-five cents. On a large bridge of the author's where the inspection was done strictly according to his ideals of detail, the actual cost amounted to one dollar and three cents per ton. Certainly, the consulting bridge engineers and the leading inspectors of structural steel should combine so as to obtain more thorough inspection by ensuring adequate prices therefor. The engineer should insist on choosing the inspectors and should invariably make the client foot the bill for their work. Of course, he should see that the client is not overcharged; but there would probably be standard fixed rates for the different classes of work, hence the question of overcharge would not be likely to arise.

The following are Hildreth & Co.'s standard instructions to their assistants concerning the inspections of steel rails and other track materials.

"Specifications for Inspection of Rails and Their Details

"*Standard Tee Rails*

"In addition to the requirements of specifications, which are clear and which should be followed closely by inspectors, attention is called to the following special instructions:

"*Process of Manufacture.*—It is important that the Inspector shall know and report upon the details of the process of manufacture, for the reason that specifications generally leave this to the manufacturer and that most of the defects in rails are the result of efforts by the mill to secure increased tonnage and the consequent neglect of those details of manufacture whereby good rails are secured. The capacity of the furnace should be noted and whether it is being crowded to handle a greater amount of steel than its rated capacity, and also the time of melting. Pouring of steel from the ladle should be slow; and the character of the tops of ingots should be noted. Formerly specifications called for stirring the steel in the ladle with a pole to bring the gas bubbles to the surface. Bottom pouring produces ingots freer from gas bubbles and segregating elements. Inspectors should watch such conditions so as to form an opinion as to the care used in pouring the ingots. The size of ingots and the number of passes from the ingot to the finished rail should be noted and an opinion formed as to whether the steel is broken down too rapidly and the rails not well finished. The distance between the saws should be watched as a check upon the temperature at which rails are finished, and this temperature should be noted. In short, inspectors should not merely pass upon the finished rails but should watch and be familiar with all the details of the process of manufacture *and must report regarding them for each order.*

"*Tests.*—All tests should be conducted by the inspectors as specified; and they

should personally choose the test specimens so as to determine whether they fairly represent the material. They should particularly endeavor to find specimens which represent any material which is doubtful, and should try to get material which has been rolled from the top of the first and the last ingots cast from the ladle, so as, if possible, to obtain test pieces in which may occur segregated elements.

"*Section.*—The section of rail shall not only be checked in the mill; but when a final inspection is made of the rails, the templates shall be frequently applied so as to test the section of at least 25 per cent of the order; and should there be discovered any variations from the templates, then every rail must be checked.

"The same procedure must be followed with splice bars; and, in addition, several joints consisting of rails, splice bars, bolts, and nuts shall be assembled.

"*Length.*—Inspectors shall frequently check the standard length of rail, and they should not entrust such measurements entirely to the mill men. Complaints of railroads are frequent regarding variation of lengths; and such variation must be discovered and prevented.

"*Branding.*—The exact branding as it appears on the rails and splice plates should be reported, and it should be seen to agree with that required.

"*Drilling.*—Drilling should be seen to be accurate; and all ends of rails should be examined to ensure that the holes are free from burrs.

"*Straightening.*—The cambering of rails should be watched as well as the straightening, and no excessive gagging permitted. Short kinks shall class rails as No. 2. Every rail must be sighted for straightness.

"*No. 2 and Short Length Rails.*—Care should be taken to see that rails are properly classed and ends painted as specified. Inspectors should keep their own record of both classes of rails and short lengths.

"*Surface Inspection.*—Inspectors must make a thorough and careful inspection of rails by daylight, examining each rail for visible surface defects such as laminations, seams, fractures, scale, etc.; and they must particularly examine webs for evidence of piping. Every rail must be walked and examined on all sides.

"*Identification.*—All accepted rails must be plainly stamped on the end with our special brand; and each rail must be carefully and finally inspected before such acceptance.

"*Reports.*—Reports should be made immediately after shipment, showing rails accepted and shipped; and copies of shipping invoices should be sent with such reports. Inspectors should be particularly alert to see that no rejected rails are shipped, and should advise us at once if such is the case.

"*Night Inspection.*—Where large orders are rolled during the night, the Inspector in Charge should arrange either to be personally on the work or to have an assistant present. Where large orders require several men at the mills, the Inspector in Charge will so advise us, so that sufficient assistance can be provided.

"*Special Notes for Girder Rails*

"In the inspection of girder rails, particular attention shall be given to see that the groove is absolutely straight and that the head is full where the tread of the wheel runs and at the points of bearing of splice plates. Special attention should be given to see that the height of rails is accurate and that the sections of joints correspond closely.

"*Splice Plates*

"See 'Process of Manufacture' and 'Tests' for Rails.

"*Bending Tests.*—Must be made as required and reported by outlining on report forms for tensile tests or on plain white paper of the same size as the reports.

"*Section.*—Must be carefully checked by templates.

"*Punching.*—Must be accurate and tested by templates. All burrs must be re-

moved and holes examined to see that no edges are cracked. Any indication of cracks is cause for rejection.

"*Bearing Surfaces.*—Must be carefully watched and frequently checked by assembling a joint with rails and testing with steel straight edge.

"*Bolts and Nuts*

"Every keg of bolts and nuts must be seen and the threads examined to see that they are clean-cut and full. Numerous nuts must be tried on bolts. Any special style of thread (such as Whitworth's Standard for foreign orders) must be known to be followed. Bending tests must be made as per specifications. Stripping tests must be made by filling up between head and shoulder of threads with washers and turning the nut on with a long-handled wrench. Bolts must twist off before threads are stripped. All dimensions must be checked. Bolts tested by bending and stripping should be placed on top of contents of keg to demonstrate that inspection has been made.

"*Spikes*

"All dimensions must be measured and every keg opened and examined. Spikes tested by bending should be sent with shipment as for bolts. Heads of spikes must be full and points clean-cut and sharp. Samples must be tested by twisting one-half turn without fracture.

"*Nut Locks*

"Nut locks must agree with dimensions and quality specified. Tempering must be done in oil. Samples chosen at random must be tested by being placed in a vise and forcing one end $\frac{1}{8}''$ clear beyond the opposite end. If it breaks or takes a permanent set, additional tests must be made, acceptance refused, and the facts reported."

A short time ago when calling at the New York office of his friend, John D. Isaacs, Esq., C.E., Consulting Engineer to the Southern Pacific Railway Company, etc., the conversation turned to the subject of rail inspection, and the author stated (as he had on many previous occasions to others, but had been contradicted) that, in his opinion, inspection costing only five cents per ton is entirely inadequate, and that first-class inspection would cost several times that amount. Mr. Isaacs replied that he had had a similar opinion for many years, and that some three years previously he had called in Messrs. Robert W. Hunt & Co., the well-known inspecting bureau, and insisted that they should furnish him with a rail inspection which would cost much more. They did so, and the result was very gratifying; for the rate of breakage of rails was forthwith reduced to a small percentage of what it had been previously. Mr. Isaac's story was so interesting that the author requested him to repeat it in writing for use in this book. He very kindly complied, and on October 15, 1915, wrote as follows:

"As a result of our study of rail failures occurring on our lines, we became convinced that the reasons for many failures of a given weight and section of rail, of which weight and section we had large tonnages that were giving good service, must be due to lack of uniformity in mill practice or to improper methods used which generally could not be detected by the methods of inspection in force. This inspection consisted

of chemical analyses of test ingots and inspection and physical tests of the completed rails.

"It appeared to us that with the methods used by the mills there was every incentive for sacrificing quality to quantity of output. From further consideration of this matter we evolved the idea that if we should so increase our inspection as to cover the rail during all stages of manufacture, we would have greater control over, or, at least, greater knowledge of the rails which were finally submitted for our acceptance. Acting on this idea, in the early part of 1912, we took this matter up with Robert W. Hunt & Co., who submitted to us, under date of March 13th, 1912, an outline of proposed details of the special rail inspection which we desired as follows:

"We will place a man night and day in either the Converting Works (if Bessemer) or Open Hearth Works (if of that material), a man night and day in the Blooming Mill Department, a man night and day in the Rail Mill, a man night and day at the Testing Machine, and four men on the inspection and shipment of the finished rails, making 12 men in all.

"In the steel producing department the men will observe and make note of the details pursued in the production of steel, as to when the recarbonizer is added, the length of time the metal is held in the casting ladle before being teemed into the moulds, the size of the nozzle used in the casting ladles, the length of time occupied in conducting the casting operation, the condition of the moulds as to smoothness, etc., and the behavior of the ingots at the stripping machine in other words, to have a general oversight as to all which may transpire in the steel producing department.

"In the blooming mill the inspectors will observe and note the length of time the ingots are kept in the soaking pit, the temperature at which they are rolled, and the behavior of the metal while being so rolled—also as to the amount of cropping which takes place at the bloom shears, etc., etc.

"In the rail mill the inspectors will observe and note the distance at which the saws are kept and thus check the temperature at which the rails are finished, note as to the squareness of sawing and the care with which the rails are stamped, not only as to heat numbers, but also as to their relative positions in the ingots from which they may be produced—also the amount of cambering which is given the rails, and their treatment upon the hot beds.

"The inspectors at the drop testing machine will observe and record the behavior of the metal under said testing, while the four other men will have charge of the final inspection of the rails as to straightness, accuracy of drilling, freedom from flaws, etc., and their loading on cars.

"This makes a force of 12 men in all.

"It is understood and expected that while these men will be present day and night in the various departments of the Works, they will not have power or authority to interfere with the operations of the mill; but, based upon their observations, if any undue things occur which, in their judgment, may be prejudicial to the production of good rails, they will notify the inspectors who have the final passing upon the rails either absolutely to reject the rails made from the said heats or else to give them extra careful inspection. If it should be for rejection, the said rails can be put aside for discussion with the higher mill authorities and for final acceptance or permanent rejection, as the gravity may justify.

"In other words, the idea is thoroughly to police the plant during the production of your rails, and thus to add a moral influence tending toward careful work upon the part of the employees of the said plant."

"Further descriptions of this special inspection appeared in the *Railway Engineering Review*, November 23, 1912, and in the *Railway Age Gazette*, March 17, 1915.

"The foregoing, together with the report forms—certificate of inspection, report of chemical and physical examination, and special inspection reports, copies of which I enclose herewith—should give a clear understanding of the matter.

"Our adoption of this special inspection in 1912 was soon followed by many other large roads, until in 1914, as stated in one of the articles above referred to, 78 per cent of all rails inspected by Robert W. Hunt & Co. were given the special inspection.

"The direct benefits to be expected are:

A more thorough compliance with our specifications.

A more careful superficial examination.

More thoroughly to insure proper discard so as to obtain sound metal.

"Should there be a departure from known good practice in the preliminary manufacture of the rails, although this could not be condemned by the inspector, it would enable him to give especial attentions to the rails manufactured under these irregular conditions, rendering the detection of poor rails more certain.

"The indirect benefits which are to be expected are:

"A more thorough knowledge, by study and comparison of different mill methods, of what is the best current practice in the present state of the art.

"Having a complete history of the manufacture, should poor service be obtained from these rails, a study of any irregularities in manufacture may lead to a solution of some of our troubles.

"On account of interruptions during the manufacture, delays and irregularities often occur; and the moral effect of having our inspectors throughout the mill will doubtless lead to more care on the part of the mill operatives to avoid departure from what is considered 'Good Practice.'

"There has been a marked improvement in quality of rails purchased by us during the last few years. This improvement we attribute to:

1. "Improved mill practice, giving a rail more free from physical defects.

2. "Improved rail sections, better distributing in the metal for uniform rolling temperatures.

3. "Improved distribution of the chemical constituents, giving less segregation and more homogeneity of material, tending to lessen the rail failures from brittleness.

4. "More thorough inspection."

"It is impossible to segregate the improvement due solely to the special inspection, but we do know that certain faulty mill practices

which have occurred at various times in the past and which have adversely affected the quality of the rail can not 'get by' under the new system; and we conclude that the special inspection is well worth the relatively slight additional cost."

In writing to thank Mr. Isaacs for his courtesy, the author requested permission to state the percentages of breaks before and after the radical change of inspection was adopted, as mentioned during the conversation in New York; but Mr. Isaacs very modestly refused on the ground that the entire improvement was not due to the said change but somewhat to betterments in the art of manufacture. To quote his own words:

"I did not give the number of breaks per ton of rail because it makes a tacit assumption that the entire improvement is due to new methods of inspection, which is not the case, as there was a marked improvement prior to the adoption of such inspection; and, therefore, a statement of this kind, while true as a matter of fact, does not give sufficient credit to improvements in the art of manufacture, due partly to this and partly to the efforts of the mill men to improve their output.

"If you will refer to my letter to you of the 15th inst., you will note that I called attention to the impossibility of segregating the improvement due to special inspection; and further than this I am not willing to go on record with a definite statement as to effect produced, whatever my opinion concerning it may be.

"About all there is to say is that special inspection is one of the important contributing causes to improvement in manufacture of rails."

It is evident from the preceding that Mr. Isaacs by inaugurating this special inspection has made an important advance in American railroad practice.

In respect to inspection of materials and workmanship in the field, the following instructions, which the author has prepared for his field forces of engineers and inspectors, will be found to cover the subject pretty thoroughly.

(A) Metalwork

First. Examine with the greatest care all of the metalwork as fast as it is delivered, so as to make sure that it has not been injured during transportation, and keep an eye on it thereafter to see that it is not injured during erection. See also that there are no missing parts.

Second. See that the metalwork goes together properly and expeditiously, and report to the Engineer all necessity for chipping or filing on account of bad shopwork.

Third. Watch carefully the riveting to see that no burnt rivets are used, that all field-rivets are driven in accordance with the specifications, and that no loose rivets are left in the work. The inspector should keep close watch upon the gauge of the air compressor, and should also see

that there are no serious leaks in the hose or the iron pipe delivering the air to the rivet hammers. A pressure of at least ninety-five (95) pounds per square inch should be continuously maintained for two gangs of riveters driving seven-eighths (7/8) inch rivets of three (3) or four (4) inches in length. For one-inch rivets of the same length, one hundred and five (105) pounds per square inch should be maintained.

Care should be taken in heating rivets to make the head end hottest, the end to be driven being heated to a cherry red. If this be properly done, the rivet will flow back into the hole, thoroughly filling it, and the head will form accurately with no tendency to spatter, as will happen if it be too hot.

All mill scale should be removed from the shank of the rivet before driving.

A pneumatic "dolly" to hold over the round head while the rivet is being driven gives very good results, and should be used when the rivets are long and must grip several thicknesses of metal.

In driving nickel-steel rivets or extra long carbon-steel rivets it is best to use a pneumatic hammer at each end while driving.

Fourth. See that all vacant spaces in the metalwork are completely filled with paint-skins or other water-proof material before the painting is begun.

Fifth. In elevated-railroad work see that during the erection of the metal the lengths of the girders are sufficiently correct to prevent all possibility of using up the spaces provided for expansion, assuming the greatest temperature of the metal to be one hundred and twenty-five degrees. See also that the expansion and contraction of the structure cannot injure the stairways.

Sixth. In drawbridges, see that the masonry of the pivot-pier is levelled off with the greatest accuracy, and that the lower track-segments are set to exact position and level, thus making a perfectly conical surface for the rollers. See also that the latter are adjusted so as to bear evenly at top and bottom against both upper and lower track-segments.

Seventh. See that the ends of draw-spans are properly adjusted by means of the shimming-plates on the rest piers. Make sure that in every particular the draw is reversible end for end; and see that all shafting is properly aligned so that there will be no binding in any of the bearings.

Eighth. See that, before the operating machinery is tested, all sliding or rolling surfaces are thoroughly lubricated, and that the turntable is cleared of all obstructions, such as nails, etc., on the lower track-segments. Then operate for a while and make a test of the machinery, after which compute therefrom the horse-power required to operate the draw.

Ninth. In vertical lift bridges see that the towers are built in correct position, and that all the machinery is located true to line and elevation; also that it is thoroughly lubricated. See that it is operated sufficiently

to loosen up the bearings and to get everything in good running order preparatory to testing for operation and correctness of counterbalance.

Tenth. In bascule bridges take special pains with line and elevation in both the structural work and the machinery, and make the moving arm as nearly perfectly balanced as possible, paying due attention to the future drying of the counterweight concrete. In respect to the machinery, follow Instructions Nos. 8 and 9 given for swing spans and vertical lifts.

Eleventh. See that all anchor bolts are set in exact position and to correct level, and that they are properly grouted in. Be careful that, when the templates for locating them are put in, the mistake of turning them ninety degrees from correct position is not made.

Twelfth. In placing the bearings or skew-backs for arches, take the greatest care that the centres are set to exact position and elevation, and that the bearings for the metalwork on the masonry are perfect.

Thirteenth. Whenever there are any adjustable rods used in a structure, see that they are properly tightened before the work is left, taking care that they are not screwed up more than is really necessary.

Fourteenth. In reinforced concrete work see that all reinforcing bars are of the right kind for the various places, that they are put in correct position, and that they are held therein so firmly that they will not be disturbed when the concrete is being placed around them. See that as soon as any forms are removed the concrete exposed thereby is given its final finish without delay, for such work can then be done at comparatively small expense, while later the cost is likely to be excessive.

(B) Rails

First. Examine all rails as soon as received, so as to see that there are no poor ones which have escaped the rail-inspector's eye, or which have been loaded for shipment after being rejected. Inspect also all other track-metal, such as angle-bars, bolts, and braces, so as to see that they are of the correct type and are delivered in good shape.

Second. See that all rails are laid to exact line and level, that they bear properly everywhere, and that they are properly spiked.

Third. In movable spans, make sure that the track-rails at the ends will not interfere with the operation of the span.

Fourth. When the rails are to be bonded, see that the bonding is done in strict accordance with the specifications.

(C) Painting

First. See that, after proper cleansing, drying, and retouching with paint, the metalwork receives its first field-coat of paint as soon as practicable after erection, and that the next coat is applied as soon as practicable after the first field-coat is thoroughly dried, but in no case before.

Second. Make sure that all paints used are of the proper color, qual-

ity, and consistency, and that no adulterants or thinners are used; also, that all paint is properly applied.

Third. Look carefully to the painting of all close spaces between metal, and see that it is done effectively with a piece of cloth, according to the specifications.

Fourth. See that all portions of the metalwork which are to rest on the masonry or which are to be embedded in the concrete receive their two field-coats of paint in due time, so as to dry thoroughly before the said metalwork is erected.

(D) EXCAVATION

First. Watch carefully all excavation so as to make sure that it is done in strict accordance with the specifications and with the City Ordinances, if there be any. See that, in doing the excavation and in building the structure, the Contractor does not obstruct public traffic.

Second. In foundation-work in cities, see that all pipes and sewers are moved properly and coupled or spliced effectively after being uncoupled or cut.

Third. Whenever there is any doubt about the proper resistance of any foundation, test it by loading it by means of a properly designed and built apparatus. Always ram thoroughly any foundation where the resistance to load would be effectively increased by such ramming. See that the material from the sides of the pits is prevented from falling in.

Fourth. See that all surplus material is removed expeditiously from City streets, and that, whenever any piece of construction is completed, all falsework, rubbish, etc., are removed from the site and are deposited in an unobjectionable place.

(E) FOUNDATIONS

First. See that the bed-rock is always properly prepared to receive the caisson or masonry, as the case may be, letting the caisson into the rock so as to provide an even bearing around the cutting edge, and levelling or stepping off or filling up with concrete to receive the latter.

Second. In elevated-railroad work, see that wherever columns are located in the street their feet are properly encased in concrete, and that cast-iron fenders are correctly set around the columns and filled with concrete and grouting, then sealed effectively against the ingress of water. See also that, after the columns are up and encased, the pavement is relaid in a substantial manner, to the satisfaction of the City authorities.

Third. When large steel cylinders are used, see that they are kept well braced with timbers on the inside during sinking, so as to avoid all possibility of collapse.

Fourth. See that proper guides are provided for all caissons and

cylinders, so that they can be kept in exact horizontal position during the entire sinking.

Fifth. See that the tops of all piers are properly finished off to receive the superstructure, taking care that all bearings are made perfectly smooth and to exact level.

(F) Caissons

First. In building timber caissons, see that the plans are followed exactly, and that the full quantum of timber bolts is used; also, that short timbers are not put in where long ones are called for. See that all timbers are properly framed.

Second. In sinking caissons, see that they are never allowed to deviate materially from correct position, and that all errors of position are corrected as soon as possible after they are discovered.

Third. In filling working-chambers of caissons, see that the concrete is packed tightly against the roof, and that no voids whatsoever are left therein.

(G) Cement and Concrete

First. Test all the cement, according to the special instructions therefor, so long before it is needed for use that the Contractor shall not be delayed by such testing.

Second. See that all cement is properly housed and blocked up above the ground, and if in barrels, that the latter are laid upon their sides, also that it is in every other necessary way protected effectively from the weather. Make sure that no dampened or otherwise injured cement is allowed to be used on the work.

Third. Inspect as soon as delivered, and if possible before being dumped on the ground, all sand and broken stone, so as to make sure that they comply in every particular with the specifications; and insist always upon all of these materials that are rejected being removed immediately from the vicinity of the bridge site. If there be any doubt whatsoever about the suitability of the sand for mortar and concrete, make a mechanical analysis to determine the gradation of grains, and prepare and test sufficient sand briquettes to settle the matter beyond the peradventure of a doubt. In some cases the stone also should be subjected to mechanical analysis. Should there be any doubt whatsoever about the quality of the concrete, standard test cubes or cylinders should be made from the actual materials and broken at the end of seven and twenty-eight days.

Fourth. See that strong and proper forms for concrete are used in the construction of all piers, pedestals, and abutments, and that all visible portions of the latter are finished off smooth, the top surface being brought to exact elevation and made perfectly level.

Fifth. See that all concrete is mixed according to the specifications, that it is put in place immediately after mixing, and that it is thoroughly rammed, joggled, and spaded at surface as specified.

Sixth. See that no injury is done to the concrete in removing the timber forms, or, if any be done, that it be properly repaired; also, that the timber be left in whenever its removal would tend to injure the work. Do not permit the removal of forms before the concrete has hardened sufficiently.

Seventh. When concrete is placed under water, see that either a trémie or proper collapsing-bucket be used, and that the water be not permitted to injure the concrete. See also that all such concrete is mixed extra rich. Make sure that the trémie is kept constantly filled with concrete.

(H) Piling and Trestlework

First. See that all piles conform, in size, quality, and straightness, with the requirements of the specifications, even if they have been already passed by the timber inspector before shipment, and reject any that are unfit for use.

Second. See that all piles are driven straight and in proper position, and that the tops are not unduly injured in driving, having the said tops banded whenever necessary to prevent splitting. See that any piles split or driven at incorrect location are drawn and rejected or re-driven to correct location as the case may be.

Third. See that all piles are cut off level at the exact elevation required, and that the caps are properly drift-bolted thereto. On curves see that the superelevation is obtained properly, and not by shimming up on the caps.

Fourth. See that all sway-bracing is bolted effectively to the piles and caps.

(I) Timber, Flooring, and Hand-rails

First. Inspect all timber as soon as delivered, marking plainly all rejected pieces; and see that all such pieces are removed from the vicinity without delay, in order to prevent their being put into the structure without the knowledge of the resident engineer. It is, of course, permissible to use the good portions of rejected timbers; but in doing so great care should be exercised to prevent the workmen from putting any poor material into the work. The fact that all the timber received had been previously accepted by the timber inspector is no reason for using unsatisfactory material; moreover, sometimes it happens that timbers which the inspector has never even seen are marked with his stamp and shipped.

Second. See that the floor system is properly laid and attached to the metalwork, that each rail bears effectively upon every tie which it crosses, and that the rails are laid straight, evenly, and to exact grade.

Third. See that the hand-railing is brought to proper alignment, and is held there in a permanent manner.

Fourth. See that all joists in highway bridges are properly dapped

on floor-beams so as to bring all of their upper surfaces to exact elevation or elevations; also, that all intermediate joists lap past each other far enough to reach entirely across the top flanges of the floor-beams. See that the outer lines of joists abut and run continuously, and that they are effectively spliced on the inside.

Fifth. See that all joists in which the depth exceeds four times the thickness are bridged at distances not to exceed eight feet, and that, when the hand-railing depends for its rigidity upon that of the outer joists, the latter are well bridged and otherwise stiffened where the posts are attached.

Sixth. See that alternate bolts attaching guard-rails to floor pass through both the flooring and the outer joists, and that all holes through the latter are bored in the central plane of the joist and not too close to mid-length.

(J) Masonry

First. Inspect all stone as soon as received, so as to see that it has not been injured in transit, and that it is satisfactory in every particular, even if it has already been passed by the stone inspector.

Second. See that all stones are thoroughly cleaned and wet before being laid.

Third. See that all mortar is mixed in the proper proportion, and that it is used on the work before any set has occurred.

Fourth. See that all joints are thoroughly filled with mortar, grouting or flushing being prohibited, and that the vertical joints are filled by the use of swords. Make sure that no voids are left anywhere in the entire masonry construction.

Fifth. See that all coping-stones are set so that the top of the pier will lie in a truly horizontal plane, and that they are kept in place by proper clamps and dowels as per plans.

Sixth. See that the exposed joints are all cleansed and pointed in a thorough and workmanlike manner, and in accordance with the specifications.

(K) General Instructions

First. See that all proper precautions against accidents to the public and to the workmen be taken during erection, and that no glaringly careless man be allowed on the work.

Second. If there be more than one contractor on the job, see that no friction arises between contractors, and that their combined work is finished in good shape.

Third. While doing everything in your power to obtain good work, avoid as much as possible worrying or harassing the contractor, and use every legitimate endeavor to aid him to complete his work expeditiously and inexpensively.

Fourth. Finally, and in short, study the specifications carefully, and do all that you can to ensure the structure's being in every respect a credit to all concerned in its designing and construction.

(L) CEMENT

In respect to the testing of cement on construction work, the following instructions, which the author has prepared for his resident engineers, will give the reader all necessary information, it being understood that, so far as is possible, no brands of cement are used except those which either the author or his assistants have previously tested thoroughly by long-time tests, and which have proved to be perfectly satisfactory:

First. In testing cement in the field, remember that it is not a series of laboratory tests which you are to make, but that your object is simply to see that you are receiving and using cement of an average quality of the standard brand or brands adopted, and that it comes up to the general requirements of the specifications.

Second. Look out for irregularities in the quality of the cement, so as to avoid using any that is either too old or too fresh, or which has been injured by dampness.

Third. Test first for fineness, second for soundness, third for activity, and fourth for rise in temperature, rejecting all cement which is unfit for use because of non-compliance with the specifications in these particulars.

Fourth. Make also the boiling test as specified in Chapter LXXIX, for if any cement fails to comply with its requirements, it is not fit to use, unless, perchance, it may be improved by ageing.

Fifth. Test all cements for the tensile strength of neat briquettes, making one-day and seven-day tests. Never pass cement on shorter time-tests than seven days, as the one-day test is by no means conclusive.

Sixth. Make, more for your own satisfaction than for any other reason, a few sand-briquette tests for seven and twenty-eight days, so as to know the value of the mortar which you are using. It would not do to rely on sand-briquette tests for the acceptance or rejection of cement, as this would delay the work too much.

Seventh. You will often have to use your judgment about passing or rejecting cement that is needed for immediate use and which fails in some comparatively unimportant point quite to fill the requirements of the specifications. Rather than delay the contractor materially, pass such cement, provided that in your opinion its use will in no way injure the quality of the work; but, on the other hand, if the rejection of the said cement will not delay the contractor seriously, insist on its complying with the specifications in every particular. Be careful not to let the contractor run in any poor cement or force it upon you because of any assumed or real necessity for haste in completing the construction.

(M) Stone for Masonry

In respect to inspection of stone for masonry, the author offers, as his idea of what stone-inspection should be, the following instructions to stone-inspectors, it being understood that they apply only to stone from quarries that have previously been investigated and found satisfactory:

First. Reject all stone containing any dry seams. These seams are often very hard to detect; but usually by a careful inspection of the surface of the stone they may be found. Sometimes a mere line is all the evidence of the existence of such seams. while in other cases they show more plainly.

Second. Reject all stone containing seams called "crow-foot," which are either open, or which are liable to dissolve out after exposure to the weather.

Third. See that no stone is quarried at a time when it is liable to freeze before the quarry-sap is out of it. Stone should be quarried at least a month before it is allowed to freeze.

Fourth. See that no powder or other explosive is used in quarrying the stone, excepting to remove ledges of useless stone, and even then make sure that no stone to be used is injured by the explosives.

Fifth. If the stone be of such a character that the quarry-bed cannot be told at a glance, the inspector must mark each stone in such a manner that it will be sure to be laid in the wall on the said quarry-bed.

Sixth. Reject all stone which is taken from any portion of the quarry that is affected injuriously at any time by frost.

Seventh. See that all stone is handled carefully after being taken from the quarry, so that no cracks are developed or other injury done thereto by rough usage.

Eighth. See that all stones are cut to the exact dimensions called for by the plans, and that they comply in every particular with the specifications.

(N) Timber in Woods and at Sawmills

In respect to inspection of timber, both in the woods and at the sawmills, the author's instructions to his timber-inspectors, as follows, will be found useful:

First. Study well and compare with the mill people all order-bills, looking carefully to the various lengths, widths, thicknesses, bevels, numbers of pieces, etc., so as to make sure that your order-bills check properly against those furnished to the mill people and against the partial order-bills furnished by the latter to their various employees, so as to avoid all possibility of errors. If any be found, correct them yourself, if possible, but, if not, refer them to the Engineer for correction.

Second. Each timber-inspector is to be provided with a special stamping-hammer of his own, that has a characteristic mark which will identify

all timber passed by him. He is to keep this hammer at all times in his own possession, so that it can be put to no illegitimate use by interested parties; and under no circumstances is he to lend it to another inspector.

Third. Each timber-inspector must study carefully the specifications furnished him, and must be governed thereby; nevertheless, there will be occasions when he must trust to his own judgment as to what timber is fit and what is unfit for the required purpose, for general specifications cannot be made broad enough to cover all cases that may arise in filling a timber bill. Where a number of inspectors are employed on the same piece of work, it will be necessary at the outset for the Chief Inspector to interpret the specifications and supplementary instructions for all of the assistant inspectors. so that the latter shall not differ at all in their requirements.

Fourth. When inspecting timber be careful to distinguish properly between the various varieties that are fit and those that are unfit for use. If not otherwise stated in the specifications, you are to accept and reject as follows:

Oaks

Accept white, cow, chincapin, post, burr or overcup, and live oaks. Reject red, Spanish or water, black, black-jack, and pin or yellow butt oaks.

Pines

Accept white, Norway, long-leaf Southern yellow, short leaf yellow (for certain purposes only), and Cuban pines; also Oregon fir. Reject Southern-red, loblolly, and Rocky-Mountain yellow pines.

Cypress

Accept red, black, and yellow cypress. Reject white cypress.

Fifth. Secure timber of as uniform a character as possible, avoiding any that shows large heart-checks or growth-checks, and rejecting any which has such defects of minor importance within one inch of face or edge of timber. Avoid all coarse-growth, open-grained timber, if other timber be procurable.

Sixth. Reject any sticks that show signs of worm-holes, decay, scorching by forest fires, ring-heart, ring-shakes, rotten or black knots, dark or discolored spots, or any other defect that would impair the strength or durability of the timber.

Seventh. Examine carefully by probing with a wire all hollow or bird's-eye knots, and should the hollow be over one inch deep, reject the timber.

Eighth. Check lengths of cutting gauges every day, as they are liable occasionally to be knocked out of position. Check widths and thicknesses at each change of the machine

Ninth. In inspecting piles, look carefully to their straightness, and see that they comply in this and in every other particular with the specifications.

Tenth. See that due care is used in handling and loading timber so as not to bruise it; and under no consideration allow it to be floated in the water after it is cut and dressed.

Eleventh. Keep a daily record of all timber accepted, so that the Engineer may be informed on short notice as to how much of any bill has been cut.

Twelfth. Notify the Engineer or other proper party of all shipments, and keep an accurate account of everything shipped, so that upon short notice a statement in respect to any uncompleted order can be made, giving the amount that has been shipped and the amount that remains to be forwarded.

Thirteenth. The Chief Inspector must make regular monthly reports to the Engineer or other proper party or parties concerning the progress of the work, quality of timber furnished, etc.; and must send in monthly statements of all moneys received and expended by him in connection with his work of inspection.

Fourteenth. Use every endeavor not to cause by your inspection any more handling of material than is necessary for doing your work thoroughly; and do nothing to give the mill people needless worry or expense.

In concluding this chapter, the author desires to emphasize his previous statement that, in order to obtain a truly first-class structure, it is necessary not only to design it properly and prepare thorough specifications for its building, but also to provide a corps of competent and honest inspectors, who, from start to finish, will examine carefully and test all materials that are to be used, and who will see that the entire manufacture and erection are done in strict compliance with the specifications.

CHAPTER LX

TRIANGULATION

THE necessity for extreme accuracy in the triangulation for piers of long bridges is not generally recognized; hence result errors in pier location that sometimes require the lengthening or shortening of the superstructure, or which involve the adoption of an unanticipated skew. There is no excuse whatsoever for any such errors in location, because the method of triangulation adopted should provide a check against not only blunders, but also even trifling variations from correctness of position, and because the Contractor should invariably, at the outset of his work, take such precautions as will prevent the occurrence of any variation in sinking in excess of that provided for in the Engineer's plans.

In the triangulations for bridges over large rivers, such as the Missouri, the author makes a practice of measuring each base-line five times and each angle thirty times; and no point is ever located without using a check from another base-line, thus providing an intersection of three lines, which theoretically should be a mathematical point, but which actually varies therefrom, generally about a quarter of an inch, and sometimes even as much as one-half of an inch, in sights of about one thousand feet length.

The author has tried both iron rods and steel tapes for measuring base-lines, and has adopted the latter as the more accurate. The objection to using rods is that it is almost impossible to run a line a thousand feet long with three rods that must always be made actually to touch each other without sometimes disturbing slightly the position of two of the rods, when either lifting or putting down the third rod. With a reliable steel tape properly handled, the extreme error in a number of measurements of the same line should be less than one-quarter of an inch in one thousand feet. This would make the probable error of the average length considerably less than that amount. If any measurement show a greater variation from the average than one-quarter of an inch to the thousand feet, it should be rejected, and another measurement should be made to replace it. This presupposes comparatively level ground for the base-line; hence, if the ground be very irregular, a greater variation may be allowed. It should, however, in no case exceed one-half inch per thousand feet.

The tape-line used should be a new one for each structure, and it should be tested at the bridge shops, in comparison with their standard. As a matter of precaution, it is well to test it in the field with another

tape that is to be set aside as a reserve and not used unless an accident happen to the primary tape. For very long and important bridges, especially cantilevers with long spans, it would be well to have the tape tested by the Bureau of Weights and Measures at Washington, D. C., or by some other testing bureau of recognized standing—such, for instance, as that of the Washington University at St. Louis, Mo. The charge for such testing is usually merely nominal. As the coefficient of expansion is not the same for all tapes, it might be advisable for extremely accurate work to have the coefficient determined for the tape to be used; but in most cases of long-span bridges this would be an unnecessary refinement. A fifty-foot tape is long enough, and is in many respects preferable to those of greater length. The author has not much use for extremely long tapes to measure distances directly between pier centres either during sinking or after the piers are finished, because this method of measurement is by no means as accurate as that of intersecting three lines on each pier and using two independently measured based-lines. There is no more difficult measurement to make correctly than one with a long steel tape between two distant points without intermediate supports; because, in the first place, the double measurement on shore and in correct position is a slow and tedious one to make, involving as it does the use of the level to obtain the sag, which must be exactly alike in both cases, and, in the second place, the conditions of wind and temperature are likely to vary to such an extent as to cause errors that are very difficult to correct. The only direct measurement that is of any real value, and which can be obtained before the falsework is up, is one made on the ice. In such a measurement care must be taken not to let the tape touch the ice, but to rest it on plugs driven on perfect line into holes therein and cut off to exact level.

All base-line measurements should be made in cloudy weather, or just after sunset, or even at night; and the temperature should be noted for each fifty feet measured, as all lengths must be reduced to those for an assumed standard shop temperature of seventy degrees Fahrenheit. Even slight variations of temperature will cause errors of importance in the length of an ordinary base-line, the change in length per degree of temperature and per unit of length being about 0.0000066. For a base-line of one thousand feet and a variation of one degree the change in length would be eight one-hundredths of an inch. This, it is true, is no great amount, but there is always a liability of there being a difference of as much as ten degrees between the average temperatures for measurements made on two different days, and as much as two or three degrees in a single measurement of a base-line. In using a steel tape it is better to start from the one-foot mark rather than from the end, unless the ring be placed back of the zero-point.

The author's method of measuring a base-line on comparatively level ground is to run in a line of stakes of at least three inches by one inch

section and from two feet upward in length, spaced at intervals of about ten feet and put into exact line and level, with a large flat-headed tack driven to line on each stake and the true base-line determined by the instrument and scratched with a knife along the top of each tack. The line is measured by stretching the tape with a uniform pull of six pounds over the line of stakes, keeping the one-foot mark or the zero-mark, as the case may be, over the centre that is cut on the hub at the end of the base-line, and scratching with a knife on the tack where the fifty foot mark on the tape comes, then starting from this point to measure another forty-nine or fifty feet, and so on until the centre of the hub at the far end of the base-line is reached. The next time that the line is measured the first length should be thirty-nine or forty feet, so as to avoid using the same tacks; and each succeeding first length should be ten feet shorter. This not only involves the use of fresh tacks for each measurement, but also prevents any manipulation of the tape so as to make the partial measurements agree with those made previously. In case that a perfectly level line cannot be obtained, the line should be divided into level stretches, and where each break occurs the length should be measured on the incline and corrected afterward for the effect of the rise or fall so as to obtain the true horizontal distance. For further directions as to measuring base-lines with a steel tape, the reader is referred to Johnson's "Theory and Practice of Surveying."

The ends of base-lines, as well as all intermediate points from which triangulation operations may be conducted, should be marked by solid and secure hubs. In protected places these may consist of six-inch by six-inch timbers, three feet or more in length, driven in the ground and cut off about an inch above the surface, the centre being marked with a tack, across which are cut two intersecting lines at right angles to each other.

If the ground be subjected to hard freezing, the timber should be increased in section to eight inches by eight inches, and the length should be such that it will penetrate the ground, if possible, about three feet below frost. The earth around the hub location should be excavated to the greatest depth of frost, then the timber should be driven in or sunk like a post and well tamped, after which a stout timber box with an open bottom and a strong cover should be placed around the hub, and the earth should be packed around the outside thereof. Finally the box should be filled nearly to the top of the hub with sawdust or dry sand. In case that the ground be very hard, or if the bed-rock be near the surface, it will be best to surround the hub with concrete, and protect it with a substantial cover of some kind to prevent displacement. If driving or carting is to be carried on in the vicinity of the hub, the latter should be fenced in by four stout posts sunk into the ground on the corners of a square of seven or eight feet on a side, the posts projecting high enough above the ground to strike a wagon-box. In locating all triangu-

lation-hubs it is essential to place them so that the operations of construction will not obstruct the view of the transitman. If there is a possibility that any of the hubs will be disturbed by the operations of construction or in any other manner, such hubs should be carefully "tied in" by reference points located some distance away. This should be done as soon as the base-line is measured.

There should be at least two base-lines, one on each side of the river and both on the same side of the bridge, or both should be on the same

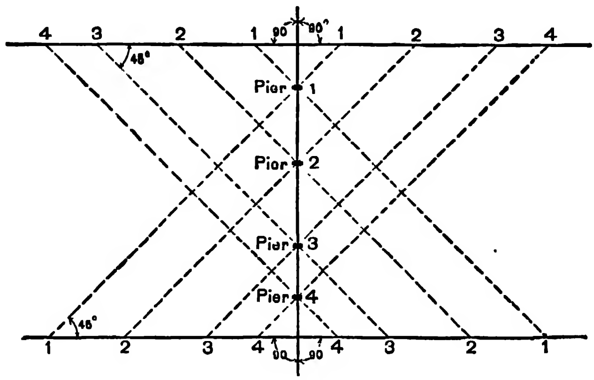


FIG. 60a. Ideal System for Triangulation.

side of the river, with one above and the other below the bridge. Usually it will be found satisfactory to locate all piers from one point on each base-line, and for that reason the ends of the base-line should be chosen so that, if possible, all the piers can be seen therefrom. If this be impracticable, or if some of the deflections would for any reason be too small, it will be necessary to put in and use intermediate hubs on the base-lines.

Base-lines, whenever it is practicable, should be run approximately at right angles to the longitudinal axis of the bridge; but this is by no means essential, and it is folly to try to make the intersection exactly at right angles, except in the following case, which represents an ideal system of triangulation that can rarely be utilized, on account of the existing conditions of shores, and obstructions both natural and artificial.

The said ideal system consists in running four base-lines, as shown in Fig. 60a, all exactly at right angles to the centre line of the bridge, and laying off thereon distances equal to those from the base-line to pier centres, so that all lines of sight will intersect the centre line at angles of exactly forty-five degrees. The advantage of this system lies in the fact that all the piers are located by direct sight without having to measure the angle, the only angles requiring measurement being the four right angles between the base-lines and the centre line of bridge, and the four other angles required for determining and checking the distance between base-lines along the bridge tangent.

The lengths of base-lines for ordinary systems of triangulation will generally be regulated by local conditions. They should usually be about *as long as the total length of bridge, or, when there is a base-line on each side of the river, as long as the perpendicular distance between opposite base-lines;* but, if necessary, they may be made as short as seven-tenths of the same. Too short base-lines will give too sharp intersections, and therefore sometimes too great variations from correctness; nevertheless sharp intersections can be employed at times by taking extra pains with the work and by employing an extra intersection as a check, in case that any discrepancy occur.

After the base-lines are measured and the hubs are put in, the next step to take is to measure the six principal angles of the triangulation. These should be measured with the greatest accuracy continuously around the limb of the transit. The programme for such operation is as follows:

1. With telescope normal, set on left station, verniers clamped. Read both verniers and record the readings.
2. Unclamp verniers, set on right station, clamp verniers.
3. Unclamp limb, set on left station, clamp limb.
4. Unclamp verniers, set on right station, clamp verniers.
5. Reverse telescope, unclamp limb, set on left station, clamp limb.
6. Unclamp verniers, set on right station, clamp verniers.
7. Unclamp limb, set on left station, clamp limb.
8. Unclamp verniers, set on right station, clamp verniers.
9. Read both verniers. Record the readings. Divide the total angle by four for mean value. Leave verniers clamped.

1. Place telescope normal, loosen limb. Set on right station. Read verniers and record readings as a check against the possibility of any slight displacement.
2. Unclamp verniers, set on left station, clamp verniers.
3. Unclamp limb, set on right station, clamp limb.
4. Unclamp verniers, set on left station, clamp verniers.
5. Reverse telescope, unclamp limb, set on right station, clamp limb.
6. Unclamp verniers set on left station, clamp verniers.
7. Unclamp limb, set on right station, clamp limb.
8. Unclamp verniers, set on left station, clamp verniers.
9. Read verniers and record. Divide total angle by four for mean value. Take average of these two means for provisional value of angle.

Then set the verniers ahead on the limb to some convenient angle, approximating the value just determined, so as to use another part of the graduated circle, and repeat the foregoing programme, thus obtaining another provisional mean value of the angle measured. Then set the verniers further ahead on the limb to some convenient angle of about the same value as before and repeat the operations until the entire limb of the transit has been utilized. An average can then be taken of the several provisional mean values thus obtained, and the result will repre-

sent the final value of the angle. To attain accuracy the limb of the instrument should be graduated as fine as twenty seconds or, preferably, ten seconds. A heavy transit with a good solid tripod will usually give better results than those obtained by using a lighter instrument. The sun should never be permitted to shine on the instrument when the angles are being observed, as it is impossible to make accurate measurements under such a condition.

In keeping notes of triangulation-work a record should be made of the date, the temperature, the condition of the weather, the direction and approximate velocity of the wind, and the names of the transitman and picketman.

If long sights are to be taken, the picketman should be provided with a pair of field-glasses to enable him to see the transitman's signals; otherwise much time and labor may be spent to no purpose. Long sights should never be taken toward the sun when it can be avoided.

The error of the sum of the angles in each of the two main triangles should not exceed two seconds in important work. Of course it is not necessary to go to any such refinement in short-span bridges; but in very long ones the error might well be reduced as low as one second. If the error in a triangle be found too large, it may be possible to avoid measuring all three angles again by looking over the notes and ascertaining from the weather conditions which angle is most likely to be at fault, then measuring this angle anew. If the second average angle reduces the total error in the triangle to within a proper limit, all right; but if not, the other two angles will also have to be measured a second time. On the same principle, if, in a group of measurements of one angle, one or two readings be found to differ greatly from the others, they may be thrown out when obtaining the average.

It sometimes happens that both intersections of the bridge tangent with the base-lines cannot be seen from one end of one of the latter. In this case it will be necessary to put in a hub on the bridge tangent far enough ahead of the hidden point to clear the obstruction, triangulate to it, and measure the exact distance from it to the hub on the base-line. This expedient was necessary in the triangulation for the author's Jefferson City highway bridge.

An example of somewhat complicated triangulation is a layout lately prepared by the author for his proposed Havana Harbor Bridge. As shown in Fig. 60*b*, the bridge tangent *AB* cuts the wharf of the Havana Coal Company near its outer end, thus affording a long base-line *BC* close to its edge on the southeast side of the said tangent; but no base-line can be obtained on the northwest side thereof. At the other end the bridge tangent strikes quite obliquely the face of a wall *DE* about twenty feet high above the water and about fifteen feet above the adjoining street, along which a base-line *AF* about 700 feet long can be obtained. The intersection of this base-line with the bridge tangent at

A falls upon a small triangular piece of ground that is entirely unoccupied, thus affording an opportunity for building an elevated double platform to support independently the instrument and the observer, and to permit the latter to sight over the corner of the wall DE to the intersection B of the bridge tangent with the long base line. Inside of the wall and about three feet below its top is a roof garden, across and along which direct measurements may be made by taping. At the outer corner of the wall is to be located an auxiliary triangulation point G visible from the far end C of the base line BC. All the angles of the triangles ABF and GBC are to be measured. If G proves to be visible from A and *vice versa*, all the angles of the triangle ABG and the side AG can be measured, but otherwise a point H on AB near the face of the wall is to be taken so that all the angles of the triangle HBG and the base GH can be measured. The distance AH can be obtained directly by taping.

The length AB can be calculated by two different systems so as to obtain a check, viz., by the triangle ABF, and by the triangle ABG, if G is visible from A, or otherwise by the triangle HBG and the direct measurement of AH. The main pier near B, occupying a part of the wharf, will be located by direct measurement, and the anchor pier near D by instruments at F and G; while the other main pier, which is some 200 feet outside of the wall at V, can be located by instruments at F and C, provided there be no vessels along the wharf to interfere. To provide for such a contingency an intermediate transit point can be located on BC, and a short base line GI can be run along the wall so as to turn off an angle of about forty-five degrees in locating the main pier.

A check on the accuracy of any triangulation work is obtained by comparing the two (or more) computed lengths of the bridge tangent between the intersections thereof with the base lines, or between one such intersection and a fixed point on the tangent on the other side of the river. The disagreement in these two measurements should be within the limit of one-half of an inch to one thousand feet. To show how accurately such work can be done, the author would state that for the Jefferson City Bridge he gave his resident engineer instructions to allow no variation from correctness exceeding three-eighths of an inch in either the main triangulation itself or in the intersections for pier centres. His instructions were followed so faithfully that no error exceeding three-sixteenths of an inch was allowed to pass in any part of the work. The whole field-force once lost an entire half day in rectifying an error of one-half of an inch in the intersection for a pier centre. This is an excellent record for accuracy, considering that the distance between base-lines on the bridge tangent was a little over fifteen hundred feet. The author is generally not so rigid in his requirements for exactness as he was in that case, the reason for such strict instructions being the fact that it was the resident engineer's first experience in important triangulation.

The triangulation for the author's Sioux City Bridge, made by Lee Treadwell, Esq., C. E., Mem. Am. Soc. C. E., with a bridge tangent about twenty-two hundred feet long between base-lines, was probably just as accurate as that for the Jefferson City Bridge, because the errors in distances between pier-centres measured on top of the falsework were actually inappreciable.

As another example of the extreme accuracy with which triangulation work can be done, the author would refer to that for his Fraser River

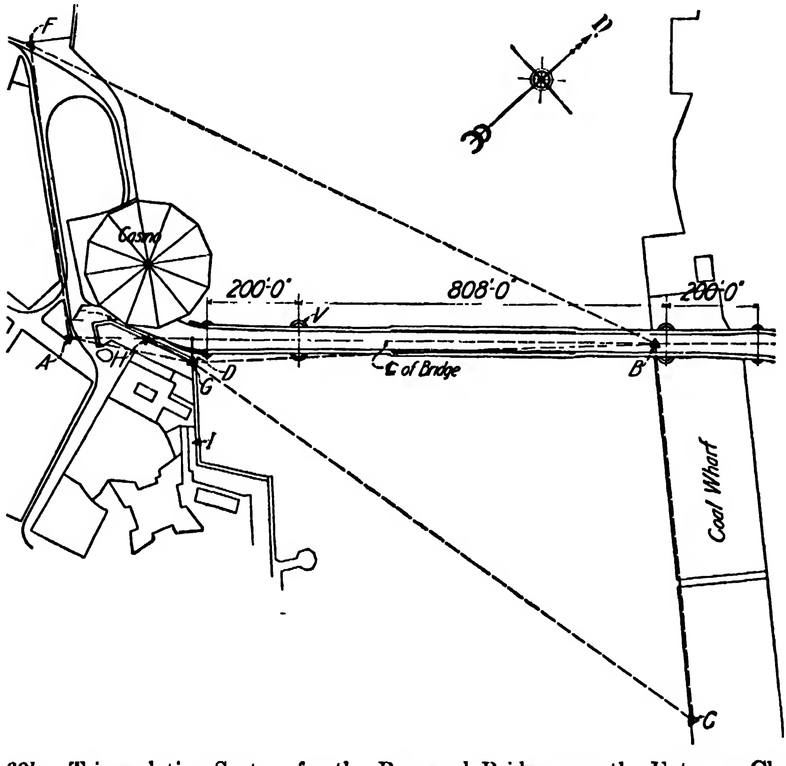


Fig. 60*b*. Triangulation System for the Proposed Bridge over the Entrance Channel to Havana Harbor, Cuba.

Bridge at New Westminster, B. C. The said work was done under his direct supervision by his resident engineer, H. K. Seltzer, Esq., C.E. The length of bridge tangent between the opposite base lines was about twenty-three hundred feet; and it was found practicable to measure base lines for four systems of triangulation. Three of the lines were of ample length, but the fourth was so much shorter than the others that the results obtained by it were finally discarded. As there was a railroad track on each side of the river near and approximately parallel to the shore line, the conditions were quite favorable for base line measurement, which was generally done in the early morning before sunrise.

The lengths of all base lines were determined with such a degree of accuracy that the largest variation from the mean was one part in 106,000 for one side of the river and one part in 63,000 for the other side. From thirty to sixty measurements of each angle were made, and the error of closure per triangle was less than one second. The probable error in length of bridge tangent obtained from three triangles was three-sixteenths ($^3/_{16}$) of an inch, and the greatest possible error was not to exceed three-eighths ($3/8$) of an inch. Although the water at the deepest place was eighty feet deep and the current ran both in and out with velocities as great as five miles per hour, the piers with their anchor bolts were so accurately located that it was found impracticable to measure the error in any span length. Work of such accuracy as this costs money—and that money generally comes directly out of the consulting engineer's pocket; nevertheless on important construction it should never be slighted in the least degree, no matter how great may be the expense involved in doing the triangulation strictly in accordance with the preceding directions.

After the main triangulation for a bridge is finished, the next step is to compute the angles to the various points on the piers that will be needed during the sinking. For a single cylinder pier it will suffice to triangulate to the centre only and for a pier composed of two cylinders a triangulation to the centre of each cylinder will be enough; but for a rectangular pier it will be necessary to locate not only the centre, but also another point near the periphery, in order to prevent the pier from being rotated about its vertical axis in going down. After the calculations are completed, a triangulation-sheet should be prepared, on which should be shown all of the triangulation with the various distances on all lines and the exact angles for all deflections.

Foresights should next be located for the bridge tangent and for all pier points, so that the transitman will never be under the necessity of turning off an angle when locating a pier. The position for any foresight is generally determined by convenience, but it should be chosen so as to avoid any probability of disturbance. Each foresight, which consists of a substantial wooden target, is located by turning off the desired angle as nearly exact as may be, putting it firmly and substantially in place, and making a provisional mark upon it. Then obtain the approximate distance L from instrument to target by either stadia or triangulation. Next measure accurately by repeating ten times or more the angle actually set off by the provisional mark on the target. The difference between this last angle and the true angle desired, as originally computed, will be a very small angle. Call it D and express it in seconds and decimals of a second. Then the desired correction is equal to $\frac{LD}{206,265}$ in the same unit as that of L. Finally, set off the correction on the target either to right or left as may be needed, and the foresight for the desired angle will be obtained. Each target is to be marked also with its characteristic

letter or number, so that its individuality may be recognized by the transitman from the most distant point of observation. All foresights should be inspected occasionally so as to see that they have not been disturbed, although any disturbance will be discovered, the first time that the foresight is used, by the three lines failing to intersect in a point.

CHAPTER LXI

ENGINEERING OF CONSTRUCTION

No matter with what care and skill a bridge be planned, nor how adequately the specifications governing its construction be drawn, if those plans are not faithfully carried out, and if the specifications are not adhered to, the result will fail to attain the standard of excellence set by the designing engineer, and to secure which his client is paying. If the result is not positively bad and dangerous, it is at least a deception and a cheat. To forestall such a miscarriage of the client's interest places a heavy responsibility on the consulting engineer who prepares the plans for the structure. This will be better appreciated, perhaps, after reading Chapter LXXVI. Such responsibility makes it necessary for his own protection, as well as for his client's, that he have direct and reliable information that the construction work is being carried on in accordance with his plans and the spirit of his specifications. As the contractor's principal incentive for doing the work is the anticipated profit, it too often happens that a short-sighted one will endeavor to enhance this profit by slighting the work. To meet this and other exigencies that arise during construction, it is customary to have an engineer reside on the job.

This resident engineer should be in the employ of the consulting engineer who prepares the plans. His function, speaking in general terms, is to supervise and facilitate the construction work. More specifically, his duties are about as follows:

1. To locate piers and abutments.
2. To give line, grade, and cut offs.
3. To inspect and test all materials entering into the permanent structure, such as sand, rock, gravel, cement, concrete, and timber.
4. To supervise construction.
5. To check daily the positions of caissons.
6. To make progress reports.
7. To make monthly estimates of work done.

Where a tramway is built out from the shore for construction purposes, the piers can conveniently be located by direct measurement made by running on it an auxiliary working line, parallel, if practicable, to the bridge tangent. Perpendicular lines are then turned at predetermined intervals for the piers; and the proper offset distances are laid out toward the bridge tangent, thus locating the pier centres and axes. If there is danger of the high water carrying out the tramway before the piers are built to above the water line, a triangulation system should be laid

out in order to be ready for such an emergency, and thus prevent delaying the work. Instructions for doing this work will be found in Chapter LX.

To facilitate the giving of lines for construction work, such as the transverse centre line of bearing on an abutment, permanent hubs and targets should be set so that the instrument-man can recover the line readily and give promptly the desired information. Care must be taken that these monuments and targets are not set too near the field of the contractor's operations; for his excavations are very apt to cause slight disturbances in the surrounding earth and thereby destroy the reliability of targets or monuments placed too close. It is a good plan to advise the contractor, preferably by a diagram, of the location of these targets and monuments and secure his cooperation in keeping the lines cleared as much as possible. Consideration must be given to the fact that as the piers and abutments build up, they will more than likely shut off the line of sight and that it will be necessary to use a back sight instead of the usual foresight in recovering such a line. Concrete monuments about a foot square and three or four feet deep, set flush with the ground surface, are easily and cheaply constructed. A six-inch lag-screw set in the approximate centre of the concrete top serves to hold the punch mark for defining the actual centre on line. The concrete should slope in all directions from the top of the lag screw, which will then serve also as a first-class bench mark.

Bench marks should be distributed at convenient locations so that elevations can be given without involving more than one set up, thus saving time and reducing the chance for errors creeping in when hurried observations have to be made. All locations, measurements, and elevations of bench marks should be checked several times at the time of their determination; and they should further be checked during the progress of the work, if there has been any reason to suspect that the monuments have been disturbed.

The inspection of materials in the field is only to supplement shop inspection and laboratory tests and not to supersede them. Metal should be inspected at the time of its unloading to see that it has not been damaged and that no pieces have been lost in transit. Timber also should be inspected at the time of unloading to see if it conforms with the specifications in regard to soundness, freedom from knots and cracks, percentage of sap-wood and proper size, and that the amount delivered checks with the invoice. Ordinarily it is the Contractor's business to do the checking, but the Resident Engineer should satisfy himself that it is done. Rock should be inspected in car at time of delivery for hardness and freedom from dirt. Sand, also, should be similarly inspected. Gravel is usually obtained from the bed of the river at or near the bridge site. It should be inspected for cleanness and tested for percentage of voids, if it is to be used for concrete. The test for voids can be readily made with a platform scale, like those used on store

counters, and a bucket. The bucket is first weighed, then filled with water and weighed again; then by subtracting the weight of the bucket, the net weight of the water is obtained, which, of course, is proportional to its volume. Empty the bucket and fill with gravel and weigh, then fill with water and weigh again. The difference between these last two weights represents the amount of water required to fill the voids. This difference divided by the weight of water filling the bucket alone gives the required percentage of voids. It is frequently possible to decrease the percentage of voids by adding coarser or finer material to the aggregate, and the engineer should experiment in order to determine whether such decrease can be effected; because, generally, the saving of cement thus effected overbalances the slight cost of adding material.

The cement should be sampled and tested after it has arrived on the work. The usual tests to be made in the field are for time of setting, soundness, and tensile strength. These should be conducted in accordance with the specifications of Chapter LXXIX.

It is desirable to have some check on the quality of the concrete being produced as the work progresses. The simplest procedure is to make small beams, say 4″ × 4″ × 26″, and then determine the modulus of rupture by bending tests. The compressive strength may be approximated by the formula,

$$f_c = (8.64 + 1.8 \log_{10} A) f_t.$$

where f_c = compression strength.

A = age of sample in months.

and f_t = tensile strength.

A better check is to take samples of the concrete from the batch as it is being placed and put into cylindrical moulds about 8″ in diameter and 16″ long. These should then be stored so as to be under practically the same conditions of temperature and moisture as the concrete in the work. These cylinders can then be tested from time to time in a compression machine at the nearest laboratory. Cylindrical samples are to be preferred to cubes, because the concrete specimen fails along diagonal planes at about 55 degrees to the horizontal. In the case of cubical specimens, the friction of the specimen on the plate of the testing machine is sufficient to give an apparent higher resistance. This sampling of the actual concrete as it goes into place and its subsequent testing have a wholesome moral effect on the contractor and lead to a more careful mixing and adjusting of the percentage of water, as a material difference can be produced in the strength of the concrete by changing this factor. Again, the knowledge of the actual resistance of the concrete as placed is of value to the designing engineer in guiding him in future work.

According to the specifications given in Chapter LXXIX, the contractor has the privilege of having any of the materials used on the work tested at other places than the site. In that case the resident engineer will send a competent inspector to each point indicated by the contractor,

but the latter must then bear all the expenses of every kind incident to such testing, including the salary, travelling expenses, and board of the special inspector. This privilege is often utilized in the case of cement, piles, timber, crushed rock, and creosoted timber.

In having such testing done at a distance from the bridge site, on account of its special character the engineer assumes a certain moral but, possibly, not a legal obligation to make such inspection final, although the specifications contain a direct statement to the contrary. On this account care should be taken to send only an experienced inspector on such special work, and in most cases the engineer should rely upon his thoroughness and judgment. If he passes a lot of material that is unfit for use in the construction, such inferior material has to be rejected at the bridge site; and immediately there arises the question as to who shall bear the pecuniary loss involved by such rejection. The contractor feels that he should not be called upon to stand it, for he has done all that lies in his power to secure good material, even to the extent of paying for the extra cost of the inspection; the supply man, often chuckling to himself, says, "You accepted the material and that settles the matter as far as I am concerned"; the client says to the engineer, "I don't see why I should be made to bear this useless expenditure—what am I paying you for?" The negligent or culpable inspector is, of course, too impecunious and irresponsible to assume the pecuniary responsibility; and the engineer is not paid a sufficiently large fee to warrant his guaranteeing the client against mistakes of his employees. If the question were brought before a jury, in spite of the specifications providing to the contrary, they would probably saddle the expense onto the client, unless it could be shown that there was fraud involved on the part of either the supply-man or the contractor.

A case of this kind arose lately in the practice of the author's firm. It became necessary to inspect some railroad ties for a large viaduct; and the only man available was a young university graduate of seven years' experience in office and field—an honor man, by the way. He was given a copy of the specifications and some sound, practical advice before starting; but the result was disastrous, for he accepted several car loads of ties, half of which were unfit for use. They were crooked, under-sized, and rotten. The outcome of the matter was that by mutual agreement the loss was to be borne equally by the contractor and the engineers, the former being punished for having dealt with a notoriously tricky supply man and the latter for their failure to select an experienced inspector. This case is quoted as a warning to all resident engineers to be careful in their selection of inspectors for the examination of materials at places other than the bridge site.

The author at various times has had occasion to inspect for his work great amounts of timber, some single orders involving as much as ten or twelve million feet board measure, and he has almost invariably had

good luck with his inspection. He usually has employed uneducated but experienced men from the saw-mills and lumber camps, preferably those from some place not too distant from (*and yet not too near to*) the district where the timber was to be cut or manufactured. The danger in choosing that class of men for inspection is that they are liable to be bribed to pass inferior material; hence one should post himself thoroughly concerning the reputation for honesty of such inspectors before engaging them.

In testing cement at the manufactory the engineer should guard himself against the possibility of the manufacturer's shipping to him other cement than that which he has had inspected and stored. It is, of course, impossible to mark all the bags, and generally the storing is done in bins before bagging; hence the only truly safe procedure is to keep the inspector at the mill until the last of the cement is shipped.

When inspecting broken stone at the crusher, the main points to look after are the freedom of the product from dirt, especially clay, the use of no unsuitable stone, and the adherence to specifications in respect to size. In some localities it seems almost impossible to secure truly clean stone, even where good rock is plentiful; because in wet weather the rocks sent to the crusher are liable to become contaminated with wet clay. This is very difficult to remove, and its effects on the concrete are bad, notwithstanding all that may be claimed to the contrary; because when little lumps of clay become mixed in the concrete, they form small surfaces where the strength is but little greater than zero. If the clay were thoroughly dry and mixed uniformly throughout the cement, that would be an entirely different condition; and it might even show an increased strength in the concrete. It is, therefore, essential that the resident engineer pay special attention to the aggregate that he uses for his concrete; and any inspector whom he sends to look after the broken stone at the crusher should be one whom nature has provided with a stiff back-bone.

The supervision of construction means seeing that the intent of the specifications and plans are being carried out. Here the resident engineer is called upon to exercise good judgment and diplomacy. He should distinguish between those operations which directly affect the integrity of the structure and those which are incidental and preparatory to the major operations. For example, the location of a derrick or the placing of a pile driver are of the incidental order, but the quality of the concrete deposited by that derrick or the position and penetration of the pile driven by the pile driver are of the major order and should be done to the satisfaction of the engineer as defined by the specifications.

While the engineer may very properly make suggestions on the incidental operations, especially if called upon to do so by the contractor, it is better policy to refrain from giving unsought advice and to let the contractor manage his own business as far as consistent with carrying out the plans and specifications. It should be remembered that the con-

tractor is being paid to do a certain piece of work in accordance with the spirit of the plans and specifications and that the burden of responsibility for so doing primarily rests on him. He should realize and appreciate this responsibility and that his compensation covers the carrying of this burden. Nothing should be said or done by the resident engineer that might be construed as a shifting or a dividing of this responsibility. Of course, if any anticipated operations of the contractor would interfere unnecessarily with the engineer's instrumental work or would tend to block the required rapid progress of the construction, the engineer has the right to advise or remonstrate, and even in extreme cases to command; but such power should be used with great discretion and diplomacy.

When piers are to be built in open coffer dams, the work of locating them is comparatively simple, for when they are once located little or no movement takes place afterward. But when piers are to be sunk by the pneumatic process or by open dredging, great care must be taken at every step, because the pier is always either moving or liable to move at any moment. In sinking piers by either of the two last-mentioned processes, the resident engineer should keep such notes that from them he can report daily as to the exact horizontal position of the cutting edge of the caisson, the position of the top of the pier, the elevation of the cutting edge, the inclination of the axis of the pier to the vertical, and the amount, if any, that the pier has been revolved around its vertical axis. The contractor can conduct his operations with much more certainty of landing the pier in its true position, if he be kept informed as to its relative position every day.

If temporary staging be used around the pier, from which to conduct the operations of construction, keeping track of the various motions of the pier will be a comparatively easy task, for the approximate alignment can be obtained from temporary points located on the staging, which points, however, need occasional checking to see that the said staging has not shifted slightly. If there be no staging, all locations will have to be made by triangulation, and, as before stated, two points on each pier will be needed in order to detect rotation. When the caisson has reached a considerable depth, however the liability to rotate is greatly lessened. After all that may be said, the work of keeping the pier in correct position will be dependent on local conditions and many varying requirements.

In respect to the levels, care should always be taken to preserve such measurements as will enable the leveller to keep a record of the vertical distance from the cutting edge to the top of the crib at each of the four corners. This will be necessary in order to determine how much the said cutting edge is out of level.

In giving the final elevations for the copings of the piers, it will sometimes be found necessary to take very long foresights, owing to the im-

practicability of setting up the level near the piers. In such cases a backsight should be taken to a bench-mark about the same distance from the instrument as the pier is therefrom, and in the opposite direction, so as to offset a possible slight lack of adjustment in the level, and to compensate for the curvature of the earth.

The method of finding the variation from correct position at both top and bottom of a caisson during the process of sinking and the preparation of the data required by the contractor for rectifying the same are somewhat complicated, consequently the said method is herewith appended. The manner in which it was evolved some sixteen years ago by the author was rather amusing. Up to that time he had left to his resident engineers the task of finding by methods of their own the daily positions of cribs and caissons; but once when visiting a bridge under construction he found that the engineer in charge was unable to solve the problem. The engineer demanded formulæ and showed several unsuccessful attempts of his own to obtain them, consisting of a complicated mess of sines, cosines, and tangents involving inextricable confusion and reaching no result. The author sat down and prepared the following demonstration, which he submitted to the resident engineer to check. All went well till the point was reached where the assumption is made that two lines are parallel when they are not. The young man exclaimed, "Here, this is all wrong; because those lines might be far from parallel, and the formula would be totally incorrect!" The reply was "If there is any serious incorrectness, you are at fault for having permitted the caisson to get so much out of position; but even if there is a great error involved, the first sinking, if properly managed, will render it inconsiderable." It was difficult to convince the young man, who had not been away from the technical school long enough to lose his awe of mathematical formulæ, that the method was proper, but after he had tried it a few times he became firmly convinced of its usefulness and its satisfactory character. Every since then it has been a part of the equipment of the author's field engineers.

Method of Locating the Position of a Caisson During Sinking

N. B. The subscripts generally indicate a direction perpendicular to the plane corresponding to the letter of the subscript.

In Fig. 61*a*, showing a top view of the caisson, let XX and YY be two coordinate vertical planes, the former on the bridge tangent and the latter at right angles thereto and containing the up-and-down stream axis $B\ A\ C$ of the caisson; *i. e.*, the vertical axis of symmetry of the latter passes through the point A. D, E, F, and G are the correct positions of the four corners of the crib or caisson. Let the position of the top rectangle of the crib at any time during sinking be indicated by the primed

letters, and that of the bottom at the same time by the letters marked seconds.

The fieldwork consists of the running in of the lines XX and YY, finding their intersections with the edges of the crib, thus locating the points B' and C' and determining their distances from the coordinate axes, and taking levels of top of crib at the four corners.

It is understood that the vertical distances from bottom to top at the four corners have been measured, marked on the timber, and recorded

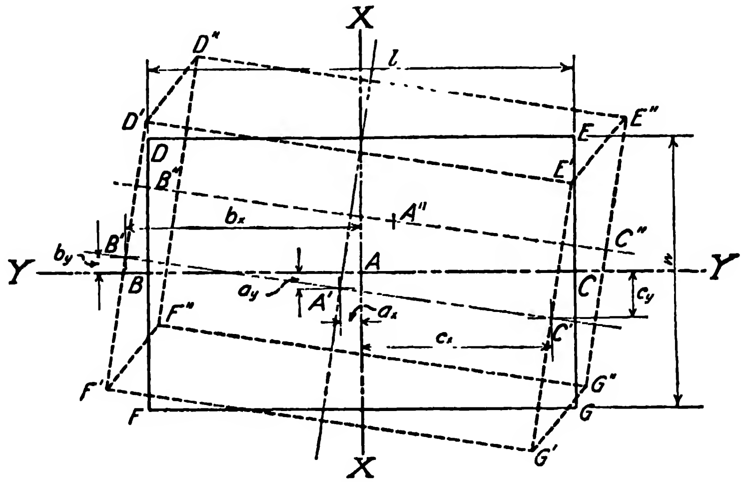


FIG. 61a. Position of Caisson During Sinking.

in the note-book, so that if the top surface of the crib is not truly parallel to the bottom surface of the caisson the elevations of the four corners at the top can be corrected accordingly so as to make the two planes parallel.

Let b_x = perpendicular distance of B' from XX.
Let c_x = perpendicular distance of C' from XX.
Let a_x = perpendicular distance of A' from XX.
Let b_y = perpendicular distance of B' from YY.
Let c_y = perpendicular distance of C' from YY.
Let a_y = perpendicular distance of A' from YY.
Let h = height from bottom of caisson to top of crib.
Let l = length of crib (FG or DE).
Let w = width of crib (DF or EG).
Let e_d = corrected elevation of corner D'
Let e_e = corrected elevation of corner E'.
Let e_f = corrected elevation of corner F'.
Let e_g = corrected elevation of corner G'.
Let e_m = mean of e_d, e_e, e_f, and e_g.

$$b_x - a_x = c_x + a_x$$

$$\therefore a_x = \tfrac{1}{2}(b_x - c_x) \qquad \text{[Eq. 1]}$$

$$b_y + a_y = c_y - a_y$$

$$\therefore a_y = \tfrac{1}{2}(c_y - b_y) \qquad \text{[Eq. 2]}$$

Equations 1 and 2 locate the position of the point A' with respect to the coordinate planes.

The amount that any properly vertical line in either of the faces $D'F'$, $D''F''$, or $E'G'$, $E''G''$, or in any parallel plane of the crib and caisson is out of position in said plane between top and bottom measured horizontally is

$$(e_f - e_d)\,\frac{h}{w} \quad \text{or } (e_g - e_e)\,\frac{h}{w}$$

But as the lines $D'F'$ and $E'G'$ are very slightly divergent from the plane XX, no error of consequence will be involved by assuming that this variation is parallel to XX, therefore the distance parallel to XX between the projections of A' and A'' on any horizontal plane is

$$x = (e_f - e_d)\,\frac{h}{w} = (e_g - e_e)\,\frac{h}{w} \qquad \text{[Eq. 3]}$$

Similarly the distance parallel to YY between the projections of A' and A'' on any horizontal plane is

$$y = (e_d - e_e)\,\frac{h}{l} = (e_f - e_g)\,\frac{h}{l} \qquad \text{[Eq. 4]}$$

The coordinates of A'' in relation to XX and YY will therefore be

$$X'' = a_y \pm x \qquad \text{[Eq. 5]}$$

$$Y'' = a_x \pm y \qquad \text{[Eq. 6]}$$

The corrected heights of the four corners above and below a horizontal mean plane are respectively.

$$v_d = e_d - e_m \qquad \text{[Eq. 7]}$$

$$v_e = e_e - e_m \qquad \text{[Eq. 8]}$$

$$v_f = e_f - e_m \qquad \text{[Eq. 9]}$$

$$v_g = e_g - e_m \qquad \text{[Eq. 10]}$$

The amount that the crib has been rotated about a vertical axis is measured by the sine of the angle of inclination (θ) of the line $D'E'$ to the line $D\,E$, or

$$\text{Sine } \theta = (c_y - a_y) \div \frac{l}{2} \qquad \text{[Eq. 11]}$$

The data to be given daily to the contractor are as follows:

1° How much too far North or South the point A' is.

2° How much too far East or West the point A' is.

3° How much too far North or South the point A'' is.

4° How much too far East or West the point A'' is.

5° How much each of the four corners is high or low above mean plane.

6° How much the crib is rotated about its vertical axis, and in which direction is the rotation.

This information is given respectively by Equations 1, 2, 5, 6, 7, 8, 9, 10, and 11.

In case that the points B' and C' both lie on the same side of YY, the sign of b_y in Equation 2 would, of course, have to be changed, making that equation

$$a_y = \frac{1}{2}(c_y + b_y)$$

In applying Equations 5 and 6, care will have to be used in regard to the signs; but it is easy to see in any case whether the terms are additive or subtractive.

The contractor should be instructed to use the engineer's height-marks at the corners when correcting the position of the crib instead of measuring from the corners of the timber or metal as actually built.

Records and Reports

The business of making records, reports, and estimates is a most important one for the resident engineer. To systematize such work and produce a uniformity of results, the author's firm has prepared a complete and detailed set of instructions for its resident engineers, from which the following is quoted:

Records and reports are for information, the latter for the present information of the Main Office, and the former for the present use of the Resident Engineer and for the ultimate information of the Main Office Records. They should be legible, concise, and comprehensive—permanent, accurate, and intelligible. This requires orderly, systematic arrangement. Blanks for records and reports will be furnished from the Main Office.

(a) *Records.*

The Following Records Are To Be Kept

1. Records of Progress of Work.
2. Daily Record of Work.
3. Material Record.

4. Field Notes.
5. Correspondence.
6. Estimates, Monthly. Fina
7. Expense Accounts (Monthly).
8. Unclassified Work Accounts.
9. Final Quantities.
10. Employment Records.

1. *Records of Progress of Work.*

Records of the progress of the work shall be made by filing the Engineering Staff Reports, amplified where necessary by notes; by filing one copy of each report as hereafter specified to be sent to the Main Office; by filing other reports; and by the records hereinafter described.

2. *Daily Record of Work.*

The daily record of work will be given by the Engineering Staff Report, amplified by attached notes where necessary. On a small piece of work where one man does all the inspection and supervision, these records may be kept in a bound diary similar to Diary No. 348, published by the Excelsior Diary Co. For all work where more than one man is employed, the daily record is to consist of a series of leaves to be fastened with McGill fasteners on card backs, or to be filed together in a suitable box, one leaf to be made out, numbered, dated, and signed by each employee. These are to be received by the Resident Engineer not later than the following morning, to be checked, countersigned, and filed. His own card is to accompany the others and give a general summary of the entire work.

SAMPLE

WADDELL & HARRINGTON Day No. 95

ENGINEERING STAFF REPORT

Job: Little River Bridge Date June 5, 1912.

The following work was done today under my supervision:

12 men concreting base Pier 2,
used 300 sacks cement—about
60 yds. of concrete. Delayed
one hour for cement.
Gave elevations for top of concrete of base.

O.K.
M.J.M

Cloudy.
My time 10 hrs. Signed A. N. Inspector.

"Daily Records" are to be made *daily* and are to be written with ink. They are to include by each man, for the work under his charge, a general epitome of the disposition of the contractor's forces, a statement, with approximate quantities, of what has been accomplished, and

such items of conditions for work, weather, and of especial moment which are of interest. Where instrument work or other engineering work has been done, a statement of what has been accomplished is to be given.

If mixing and laying concrete, there must be stated the number of yards mixed and the number of barrels of cement used. (This latter item will be gotten from the Contractor's office or from the man keeping count of barrels.) If driving piles, there must be noted the number of piles driven and the approximate penetration for all piles.

If the bridge is not in or near a town, and the contractor has to maintain a camp for the boarding of the men, the Engineering Staff shall make arrangements to board with the contractor, unless there is some place in the vicinity where board can be obtained. In any event, where the work is away from a town or city so that the Engineer's staff can be in office after working hours, the daily, weekly, and all other reports can be made out then; but if the work is in a town or city, the crew will become scattered after working hours. In that case each man must turn in his report promptly at 7 A.M. of the morning after the day which the report covers, so that the Resident Engineer or his assistant can mail his daily report not later than noon. If this is carried out, the matter of getting up the reports will take a very small amount of time each morning.

If orders for special work or special instructions to Contractor have been given, note should be made thereof for the order. Give details in figures or approximate figures; for instance, do not say: "Piles we have been waiting for came in," but say: "50 piles in today, have been waiting for them since May 20th."

3. *Material Record.*

A record of materials received is to be kept in a bound book, and entries are to be made not later than the day after the material is unloaded.

The Contractor is to be requested to furnish this daily information in suitable memoranda; and he may be advised that the make-up of his monthly estimate will depend on the promptness and accuracy of his information. Car numbers and shipment numbers are to be given. Materials delivered by wagon, boat, or raft are to be so noted.

The daily record sheets are to contain sufficient information to check approximately the Contractor's data.

It Is Not the Duty of the Engineer to Check or Receive Material.

He is in no way responsible for materials or their storage.

The Engineer shall not make out detail bills of materials or in any way assume responsibility for the amounts ordered. He shall, however, determine in a general way the times that various materials should be received and shall remind the Contractor of his needs.

The Contractor shall be required to furnish likewise daily a memorandum, giving the number of men and foremen working each day and the disposition of forces. Details of time and payment are not desired but merely the number of men.

In case the Purchaser furnish certain materials, he shall furnish also a material man to receive and receipt for such materials. This is not the Engineer's duty. If the Purchaser has no staff on the ground the Resident Engineer will employ a suitable man whose salary, together with all expense involved in looking after the Purchaser's material, shall be paid by the Purchaser, usually through the Contractor under Unclassified Work.

4. *Field Notes.*—(We recommend Dietzgen Books—Field Book 400: Level Book 410.)

Full and definite field notes are to be made of all surveys and measurements. They should be complete in every detail and prepared in a neat and legible manner. Notes and sketches should be clearly made with a hard pencil so that they will not become blurred.

An office field book is to be kept in the office and not taken on the work; and into this are to be copied the notes from the field books used in the field. This copying may be avoided by the use of loose-leaf notebooks, the sheets of notes being merely transferred to the office book. Such notes as are needed again in the field, as, for instance, distances or bench marks, may be copied, as required, from the office book.

In using the loose-leaf system, each leaf should bear the date of work and the name of the compiler so as to be complete in itself.

When corrections or additions are made to field notes after they are placed in the office, they should be in ink or colored pencil over the signature of the corrector and with date of correction given. No erasures in field notes are permissible. Erroneous work is to be crossed out and correct work given near by.

The details of handling field notes will be left as much as possible to the preference of the Resident Engineer, but the following must be included. Each book is to be indexed, the indexing being done as the notes are put in the book. Each book is to have a title in ink on the first inside page, giving the name of the Engineer and a page or so of information about its contents. There have been numerous books turned into this office without title or name or marks to tell to what the notes apply. It is well to explain in preface-remarks that certain notes are preliminary or merely approximate, and to designate fully those which are final.

Title and index every book of an entire series, for although you may send them in tied together, they are likely to become scattered.

The value and character of field notes are determined by the ease with which any one, other than the maker, can follow them through and understand what was done.

A change of personnel may be made at any time, and the notes should be in such condition that the incoming engineer may have decipherable information. Especially is it necessary to give full explanation of preliminary survey notes, such as hydrographic maps.

Note thus:

"This survey was made for the preparation of a Hydrographic Map of the Missouri River near Kansas City for John Doe, work done from April 10, 1906, to June 1, 1906. Party ——————"

4a. Record of Pile Driving.

An engineer's Level Book No. 410 is to be used for making record of pile driving. For pier construction a sketch of the pile plan should be made in the book and the piles should be numbered. Columns are to be provided to give Pier No., Pile No., Length delivered, Length put in leads, Date Driven, Time Started, Time Finished, Elevation of Top, Cut-off, Elevation of Bottom, Length below cut-off or below base of pier, Penetration for last 5 blows, Drop of Hammer, Weight of Hammer, Remarks.

4b. Record of Pier Sinking.

The records of Pier Sinking are to be kept on special sheets, and are to be so arranged that there is provided a continuous record for each pier. No copy need be sent to the Main Office except in cases of special difficulty, etc.

When, during the progress of work, data are sent to the Main Office for the designing of special parts, etc., the notes are to be reduced to profiles and maps, but copies of the original field data are also to be sent in so that the plotting work may be verified.

5. *Correspondence.*

Press copies, or carbon copies, or preferably both, are to be taken of each letter written by the Resident Engineer. All correspondence must be properly fastened together in order, and complete files are to be sent to the Main Office when the job is finished. All formal written instructions and notes to Contractor are to be handled as correspondence. Roll copy-books can be used, requiring no copying press.

Mark "Received, date ——" on all letters and papers coming to you. This is particularly important in the case of blue-print plans, etc. Many times revised prints are sent out and these should be substituted for the original drawings immediately and without fail. The old prints should be marked "Void" in evident manner, and then filed away till completion of job, and after final settlement they should be destroyed.

At completion of job the blue-prints are to be destroyed, except those giving "final dimensions" as hereafter noted.

6. *Monthly Estimates.*

A bound book is to be devoted to the preparation of monthly estimates and no other notes included therein. These notes need be only rough pencil notes, but are to be put in the book so they can be referred to. The estimate is made up by allowing the Contractor a certain value for all raw material delivered and certain fixed prices for quantities of work done. The cost of the raw material used in that work is deducted from

the total allowable value of the said work and the difference is credited to the Contractor.

The specifications read: "On or about the first day of the month the Engineer shall prepare accurate estimates of the value of materials furnished and work done to date." Thus there is some latitude as to just what day the estimate runs up to—presumably, of course, to the 1st, but it may be to the 27th or the 28th or to the 3d or 4th, if desirable. The estimate forms are made so that each monthly estimate is a complete statement of the work from the beginning, and, except for the statement of money already paid the Contractor, is entirely independent of every other estimate.

Each estimate can, therefore, be made by adding the increments for the current month to the sums previously given, or by making independent figures; thus permitting a possible inaccuracy to be easily corrected.

All items payable under the contract are to be included in the estimate sheet, so that the entire accounts may be kept clear. This applies to such items as extras, bonuses, lump sums, etc.

(*a*) *Value of Material Furnished.*

Usually in the contract there will be fixed schedule rates, to be used in valuing materials furnished; but if these are not given, the Resident Engineer should investigate the cost of the materials delivered and unloaded and fix equitable rates. A close approximation will suffice, for these figures are merely payments on account, and they all disappear in the final estimate.

If the material record is complete, the quantities there given combined with the rates so fixed determine the value of the materials delivered at site. If the material record is incomplete, it is necessary to measure the amounts of all material on hand, including that which has been placed in permanent position, and that which has not yet been used.

Under the items on the Estimate Sheet of the various materials delivered at site give the quantity, rate, and value.

(*b*) *Value of Work Done.*

In the contract there are given unit price values for various kinds of completed quantities. The value of the work done will be the value of the completed item less the value of the material. For instance, if timber delivered at site is worth $20 per thousand, and timber in place is worth $35 per thousand, the value of the work done is $15 per thousand. This is so arranged on the estimate sheet.

Under the items of various final quantities place the quantities completed to date, as ——— cubic yards of concrete, ——— lineal feet of piles in place, etc., the contract unit price, and the resultant value. Then, under the column marked "Previously Estimated on this Sheet," give the value of the raw materials used in the completed quantity at the prices at which you valued them delivered. The difference is carried forward to the last column and represents the value of the work done

WADDELL & HARRINGTON, CONSULTING ENGINEERS, KANSAS CITY, MO. For Ft. Smith Van Buren District, Ft. Smith, Arkansas.

Contract No. 1
Estimate No. 5

Estimate of Work Done by Kahmann & McMurray. During Month of March, 1911.
On Substructure—Ft. Smith-Van Buren Free Bridge.

Items	Total Aggregate of Work Done and Material Furnished to Date	Schedule Price	Total Aggregate of Value to Date	Previously Estimated on This Sheet	Difference	Remarks	
Metal delivered at site....	100000 lbs.	$0.035	$3500.00	....	$3500.00		
Metal erected...........	71700 lbs.	0.045	3226.50	$2509.50	717.00	71700 at .035 =	$2509.50
Caisson timber delivered...	900 M	20.00	18000.00	....	18000.00		
Caisson timber in place....	530 M	30.00	15900.00	10600.00	5300.00	530 at $20.00 =	10600.00
Sand delivered at site.....	6000 c. y.	0.75	4500.00	....	4500.00	Stone 550 c.y. at $1.00 =	550.00
Broken stone del. at site...	7850 c. y.	1.00	7850.00	....	7850.00	Sand 300 c.y. at 0.75 =	225.00
Cement delivered at site...	9500 bbl.	2.00	19000.00	....	19000.00	Cement 720 bbl. at 2.00 =	1440.00
							$2215.00
Concrete in abutments....	600 c. y.	11.50	6900.00	2215.00	4685.00	Stone 3000 yd. at $1.00 =	$3000.00
Concrete in shafts of piers..	3340 c. y.	9.00	30060.00	12252.50	17807.50	Sand 1670 yd. at 0.75 =	1252.50
Mass of foundations.......	4725 c. y.	18.50	87412.50	26900.00	60512.50	Cement 4000 bbl. at 2.00 =	8000.00
							$12252.50
Piles delivered at site......	3770	0.10	377.00	....	377.00		
Piles in place............	980	0.50	490.00	98.00	392.00	Stone 3200 yd. at $1.00 =	$3200.00
Extra bills previously rend.	....	....	835.25	....	835.25	Sand 1600 yd. at 0.75 =	1200.00
						Cement 4200 bbl. at 2.00 =	8400.00
Extra bills No. 3 attached..	....	....	88.85	....	88.85	Timber 470 M at 30.00 =	14100.00
Extra bills No. 4 attached..	....	....	250.81	....	250.81		$26900.00
			$198390.91	$54575.00			

Total Amount of Estimate to Date......	$143815.91
Ten per Cent Reservation..............	14381.59
Net Amount of this Estimate...........	$129434.32
Previous net estimate Feb. 1, 1911.......	84652.38
Amount Payable......................	$44781.94

We certify this estimate is correct.
WADDELL & HARRINGTON,
Consulting Engineers.
Per F. M. Cortelyou.
Resident Engineer.

FIG. 61*b*. Monthly Estimate Sheet.

on the materials. A careful examination of the accompanying estimate (Fig. 61*b*) will make plain the method. This same method of figuring applies to any completed item. For instance, from the gross value of concrete is to be deducted the value of the stone, sand, and cement composing it. Likewise Mass of Foundation in place for ordinary pneumatic caissons consists of concrete and timber, hence from the gross value of the Mass of Foundation in place is to be deducted the figured value of the concrete and of the timber in place composing the Mass of Foundations.

(*c*) *Bills of Unclassified Work.*

All bills due on account of work done on any contract for which provision for payment is not made in the contract are to be made out on the form shown in Fig. 61*j*. Such items are to be referred to as "Unclassified Work."

The Contractor is to make out the bills on these blanks, providing as many copies as desired. He should, of course, first submit to the Resident Engineer the details of the bills and have them in acceptable condition before rendering.

Where the letter ordering the work is long or involved, or the work lasts over a number of months, it may be pasted to the first bill under it. When possible it is better to copy the letter each time.

Detailed payrolls and material bills are to be sent to Waddell & Harrington, Main Office, for file.

Bills for Unclassified Work are to be cleaned up each month, and all such work is to be included on the monthly estimate. The Contractor should be advised that all bills for Unclassified Work must be rendered promptly month by month, if they are to receive consideration.

Unless special orders are given, there are to be five copies of the estimate made. Four of these are to be sent to the office; and after being checked they will be forwarded.

One copy is to be retained by the Resident Engineer.

One copy is for the Office.

One copy is for the Contractor.

Two copies are for the company.

The usual items given by the estimate will be as follows:—

Superstructure under Different Classifications.

Riveted Truss Spans

Pin-connected truss spans.

Lift Span.

Towers.

Girders, etc.

Metal delivered at site.

Metal erected.

Metal riveted.

Metal painted and completed.

Decking.

Timber delivered at site.
Timber in place.
Rails and fastenings delivered at site.
Rails and fastenings in place.

Falsework Material.

Timber delivered at site.
Timber in place.
Piles delivered at site.
Piles in place.
(N. B.—Usually no allowance is made for falsework.)

Substructure.

Metal delivered at site.
Metal erected.
Excavation on land.

Caisson timber delivered at site.
Caisson timber in place.

Sand delivered at site.
Broken stone delivered at site.
Gravel delivered at site.
Reinforcing metal delivered at site.

Concrete in ———.
Concrete in ———.
Concrete in ———.

Mass of Foundations in place.
Bases of Piers in place.

Foundation Piles delivered at site.
Foundation Piles in place.

Unclassified Work Bills previously rendered.
Unclassified Work Bills attached.

7. *Final Estimates.*

The final estimate will contain the exact final quantities of the various items arranged for in the contract; but as in most cases all raw material delivered will have been incorporated into the items for payment, the valuations for raw materials delivered are omitted entirely.

This may, likewise, apply on any estimate. When all of a given raw material has been converted into items of final quantities, its valuation as material delivered may be dropped. For instance, after all the concrete is in place it may be valued at contract price and no deduction made for value of separate materials, and no mention need be made of valuation for these materials as delivered. This is to be applied only as the

items of the contract are completely finished, but never before, even though the amount of a material delivered and the amount consumed are identical.

As all the estimates except the final are for payments on account, it is not necessary to carry out the figures of quantities to the last unit. They should be so figured and recorded in the estimate book, but the nearest even figure may be given on the estimate, thus facilitating figuring and checking. For instance, if there have been delivered exactly 1,287.2 cu. yds. of stone, the figure may be given as 1,290 cu. yds. or 1,300 cu. yds. without impropriety. Final quantity figures should all, of course, be given exactly after having been carefully computed and checked.

8. *Unclassified Work.*

The specifications are so written as to include every kind of work that it seems will be needed to complete the entire construction. Work not classified or included under the classifications given is to be done under written order, which written order must be delivered to the Contractor by the Resident Engineer before the work is done. No orders for Unclassified Work will be sent from the Main Office to the Contractor, but must pass through the hands of the Resident Engineer to be recognized in making up the estimate.

Extra claims advanced by the Contractor after the work is done will not be allowed.

The Resident Engineer will keep accurate accounts of time, labor, and expenses for materials; and as all such orders are to be in his hands before any work is done, he is in a position to know definitely just what has been ordered and how much should be allowed. The work of the men must be watched with sufficient alertness to see that they devote their entire time to the duties assigned. Under ordinary conditions it will not be necessary to employ a special man to keep track of labor or material used in doing Unclassified Work; but the Inspector supervising such work shall keep a record of the amount of labor and material employed.

Inspectors keeping such records should compare the time of the labor charged to Unclassified Work with the Contractor's time-keeper. This must be done daily, as by so doing disputes will be avoided. Contractors must report daily to the Resident Engineer's office the number of men employed on all such work so that the Resident Engineer may have a check on the bills when rendered. The Inspector must keep a record and turn it into the Resident Engineer daily so that it may be compared with the Contractor's daily report. Where the unclassified or percentage work is of some magnitude and promises to last over some months or demands an undue amount of the time of the Engineering Staff, a special timekeeper or inspector is to be employed; but he will be paid by the Purchaser on the *Bills of the Contractor*.

Before giving any order for unclassified work, the Resident Engineer should consult the Main Office. No extra work is to be considered with-

out a careful reading of the contract to find if the work in question has not been already covered, or at least understood and implied to be covered in the contract. In case of emergency, if the Resident Engineer is uncertain of what stand to take, he may so express himself to the Contractor, advising that he will keep account of time and cost to be used if the work is finally allowed as an extra after consultation with the Main Office.

It must be borne in mind that the intent of the specifications and contract is to produce a finished structure, and that all incidental work and materials therefor are implied. Contractors will often claim preposterous extras with the idea that, if they are allowed, the Contractor is that much ahead. For instance, in the case of a pneumatic pier a Contractor claimed an extra for sealing the cutting edge of the working chamber, although palpably such a pier could not be constructed without sealing the cutting edge any more than it could be without driving nails. The price per yard to be paid covered a finished pier ready for use, and not one without the cutting edge sealed.

9. *Record of Final Quantities.*

The Resident Engineer is to prepare a book giving final dimensions and quantities of all constructions. This book should include nothing else and should contain only final figures. Little sketches giving dimensions are good, but if these are so complicated as to require undue time, a folded blue print plan may be pasted in the book and the final dimensions clearly marked "Final." Accompanying the sketches or drawings are to be the abbreviated calculations for final quantities.

Any other data throwing light on the construction is appreciated. These may be dates of starting and finishing, highest water, rate of sinking, rate per day of erection, etc.

Endeavor to include everything of interest to one looking over the records ten years hence, and have it all in the one book so that the complete final details of the whole construction may be found together and in order.

The title page is to be marked "Final Quantities for ——— Bridge"; and any explanatory notes that are needed are to be given fully. This book is to be so complete that no other notes need be referred to in order to determine the final sizes and position of each part of the structure.

(*b*) *Reports.*

Daily Reports

The following reports are to be prepared daily.

1. *Daily Progress Reports on Substructure.*

The Resident Engineer is to fill in every day the columns that are marked with an asterisk on the blank furnished for that purpose (see Fig. 61*c*); and in case of all piers sunk by either the pneumatic or the open-dredging process, he is to make daily observations of position and

is to record the same, together with certain other information, on the special blank form provided. (See Fig. 61*d*.) These reports are to be sent every night to the home office.

2. *Daily Progress Reports on Cement Tests.*

Whenever any special tests on cement are being made at any other place than the bridge site, the Inspector in charge of the tests is to make a daily report to the Resident Engineer, using the form shown in Fig. 61*e*.

3. *Daily Progress Reports on Superstructure.*

The Resident Engineer is to fill in every day the columns that are marked with an asterisk on the form furnished for that purpose. (See Fig. 61*f*.) This report is to be sent each night to the home office.

4. *Daily Progress Reports on Reinforced Concrete Structures.*

The Resident Engineer is to fill in every day the columns marked by an asterisk on the blank provided for the purpose (see Fig. 61*g*), and is to send the same each night to the home office.

Weekly Reports

The following reports are to be sent to the office each week, preferably being mailed Saturday night.

1. *Percentage Report of Work.*

This report is general and can be applied to substructure, to substructure and erection, or to erection alone, or it can be used for reinforced concrete structures. The information is intended to be approximate only, and the object of the report is to give the general conditions of the work at a glance. (The form to be used is shown in Fig. 61*h*.)

Under materials, the approximate percentage of each material received is to be shown by one color or by hatching, and the percentage of the material used is to be shown by another color, or in black. On the blank lines materials not mentioned may be included. The amount of each material available is thus readily seen. On the table of "Percentages of Work Completed" several different parts of the work can be shown, each by a separate line; and one line should be given for the contract as a whole. A straight line should be drawn from 0 per cent at date of starting to 100 per cent at date of completion for the job as a whole. Each week only the parts of the lines for that week need be drawn—the prior parts of lines will be filled in by the office. Each line should be labeled or referred to the labels below. It will be noticed that the months are considered as of four weeks each, and such rough approximation will be sufficient for this report.

2. *Weekly Chart of Progress.*

This report is made by marking with colored pencils the condition of

work on a small drawing of the general layout, as indicated on sample. (No illustration is herein given.)

It is desired that these weekly reports reach the office promptly; for copies are sent out to the client and to the Contractor from the Main Office. General notes in a sentence or two should be written on the chart to amplify the information there given.

Monthly Estimates

The monthly estimates are to be made out as described above, and, unless otherwise directed, all copies but one are to be sent to the Main Office, from which they are distributed.

Cement Reports

Reports on the testing of cement are to be made on the Cement Report Sheets marked CR1. (See Fig. 61*e*.) These are made to include tests of two samples. These reports are to be filed in the office of the Resident Engineer; and on the completion of all tests for a given car or bin or shipment, summarized reports are to be made on sheets marked CR2. (See Fig. 61*i*.) A copy of this summarized report is to be sent to the Main Office.

When the tests of fineness and soundness for any given car are completed the Contractor should be notified by letter, thus: "Preliminary tests on Car No. ——— are good," or "show doubtful and will be repeated." When the seven-day tests are completed, give the final word notifying the Contractor by letter advising that Car No. ——— "has been tested and found satisfactory and is hereby accepted"; or if rejected so state, and add "Please arrange for immediate removal."

Report on Materials

In general there will be no regular reports for inspection of material other than cement and steel. Usually where lumber, stone, sand, and similar materials are examined, no report need be made, the advices that such materials are received and unloaded being construed to mean that they have been examined and accepted. For certain cases, such as lumber to be creosoted, notations on the shipping invoices are sufficient. For special cases application may be made to the Main Office, and special blanks will be furnished.

Unclassified Work Reports

All unclassified work is to be reported upon from time to time in sections, as the said work is partially completed, using the form shown in Fig. 61*j*.

Reports on Cost Contracts

Whenever work is done according to the "Cost-Plus-Percentage" or the "Cost-Plus-Lump-Sum" method, the monthly statements are to be made out on the form shown in Fig. 61*k*.

Special Reports

Whenever special reports are made, they are to be written out in full and sent to the Main Office, a copy being retained.

Any special work, such as experiments or investigations for determining special details, are to be reported in full, so that there may be a record complete of the findings and conclusions.

Report on Plant

After the Contractor has assembled his plant and is about to proceed with work, make out a Special Report on Plant. Include a full statement of plant on hand, and whether, in your opinion, there is likely to be any delay in the progress of any portion of the work owing to the absence of any plant or equipment. State the Contractor's reason why such plant is not installed, where it is at present, and when he expects to have it on the ground.

State the type of each pile driver used, the weight of its hammer, and the length of the leads. Give the type and capacity of each concrete mixer and stone crusher on the ground. For jetting plants state the size of pumps, size of suction and discharge, capacity of boilers, what amount of water is available and at what pressure it can be delivered at the jet. State the number of compressors used and the size of each, the steam pressure under which these work, the corresponding air pressure, the number and size of receivers, and the type and size of the air locks and of the working shaft. Give number and capacities of hoisting engines. Give number and location of derricks. Give a list of grab buckets, orange peel buckets, trémies, concrete buckets, etc.

Practically all of the above information will be furnished by the Contractor on request.

When new plant is provided, a supplemental report is to be sent in.

The equipment usually provided for the Resident Engineer includes the following:

List of Material for Field and Office

1 Transit	1 Cash Book
1 Level	1 Letter Copying Book
2 Steel Pickets 3/8"	Blueprints of Substructure
1 Level Rod	Blueprints of Superstructure
2 Steel Tapes	Copy of Specifications
1 Metallic Tape	Estimate Sheets
1 Extra Plumb Bob and Line	Contract Prices
1 Hand Axe	Writing Paper
1 Chopping Axe	Large Envelopes
1 Box of Tacks	Small Envelopes
1 Level Book	Pens and Pencils
1 Transit Book	Black Ink
6 Small Note Books	Red Ink

If Cement Is To Be Tested at Site

1 Testing Machine	1 Coal Oil Lamp
1 Nest of Sieves	½ doz. Galvanized Tin Pans
1 Small Balance Scale	1 Cement Record Book
1 doz. Moulds	1 Office Lamp
½ doz. Panes of Glass 6″ × 8″	1 Boiling Outfit
1 Heavy Pane of Glass 13″ × 13″	1 Damp-box
1 Graduate	

If Measurements Are Made by Triangulation

2 Wooden Picket Rods	50 Pieces Tin 1″ × 2″.
1 Hand Saw	1 Thermometer
2 Small Brushes	1 Spring Balance
1 Can of White Paint	1 Centre Punch
1 Can of Venetian Red Paint	

It is hoped that the blank forms given in this chapter, which have been evolved by the author and his firms during the last three decades, will prove useful to the engineering profession, as they represent the result of wide experience and much hard thought and labor. The one given in Fig. 61*b* for the Monthly Estimate Sheet was prepared in its present form by the author himself in 1889 for the Sioux City Bridge over the Missouri River. He has employed it ever since; for he can see no way in which it can be improved. In each case it gives a quantitative history of the entire construction up to date.

It has not been considered necessary to furnish an example of the graphic method of recording the progress of construction, because a simple explanation of its use is all that is needed. The *modus operandi* of employing it, as indicated in the preceding "Instructions for Field Engineers," consists in showing with different colored pencils on certain lithographed sheets containing the general plan and profile of the structure (which sheets, at the inception of the field work, are furnished in ample numbers to the Resident Engineer by the Main Office), the different classes of work done to date, each class being represented by a special color. This method is very effective, because it indicates at a glance the total progress of the entire work in all its details for the different dates when the records were made.

The manner of using these various forms is so simple and obvious as to require no explanation.

In concluding this chapter it is well to state, for the benefit of the younger members of the engineering profession, that the Resident Engineer should never for a moment forget that his employers, the Consulting Engineers, when placing him in charge of the work of construction, entrusted to his care their professional reputation, the most valuable of all their worldly possessions; and that he should always so conduct himself as never to give cause for any one to attack it on account of any legitimate or tenable reason.

FIG. 61c

DAILY PROGRESS REPORT SHEET ON SUBSTRUCTURE

Note—Figures on this sheet merely approximate. Sheet No. 4

Resident Engineer, fill in columns marked *

WADDELL & HARRINGTON
CONSULTING ENGINEERS
KANSAS CITY, MO.

DAILY PROGRESS REPORT ON SUBSTRUCTURE OF

No..............

Name of Structure.................. Date...............

QUANTITIES	Total Estimated	In Place Last Report	Placed Today*	Total in Place	Work in Progress Today*
Timber in caissons and cribs					
Concrete in pier bases					
Concrete in pier shafts					
Concrete in pedestals					
Concrete in					
Metal in					
Embankments					

MATERIALS	Amount Required	Total Used	Used Today*	Left on Hand*	REMARKS*
Caisson and crib timbers					
Cement					
Sand					
Stone					
Piles					

Fig. 61c—*Continued*

DAILY PROGRESS REPORT SHEET ON SUBSTRUCTURE

Note—Figures on this sheet merely approximate. Sheet No. 4

Resident Engineer, fill in columns marked *

FOUNDATION EXCAVATIONS AND PIER SINKING

River Piers—Nos.	1	2	3	4	5	6	7	Work in Progress Today*
Final elevation, cutting edge								
Settled today *								
Elevation today *								
Land Excavations at								
Total excavation required*								
Total last report								
Excavated today *								

CONTRACTOR'S FORCE*			ENGINEERING STAFF*		
No. Men	Plant	Worked at	Name	Hours	Worked at
	Supts., Clerks, Watchmen, etc.,				
	Total Men				

Resident Engineer

FIG. 61*d*

PIER LOCATION REPORT SHEET

WADDELL & HARRINGTON
CONSULTING ENGINEERS
KANSAS CITY, MO.

PIER LOCATION REPORT

Name of Structure..

Pier No........... Date............ Time Record Made.............

Probable Final Elevation Cutting Edge........

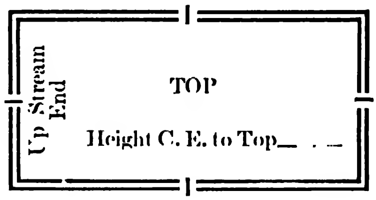
Average Elevation Cutting Edge To-day.......

Average Elevation Cutting Edge Last Report...

Settlement in.........Hours...........Feet

Distance Still to go.....................Feet

Elevation Water Surface...................



Elevation Ground Line..................... Elevation of Lowest Corner........

Immersion...............................

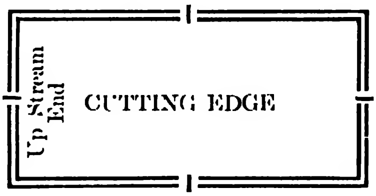
Penetration.............................

Air Pressure on Compressor Gauge............

Method of Excavation.....................

....

....



Concrete Placed Since Last Report...........

Timber Placed Since Last Report............. Elevation of Lowest Corner.........

Kind of Material Excavated...

....

Instructions to Contractor...

....

....

....

....Resident Engineer

NOTE.—On diagrams draw lines indicating bridge tangent and transverse centre line and give distances of centre points of sides and ends of cribs from true lines. Mark low corner and give amount of each other corner above low corner.

Fig. 61e

FORM FOR DETAIL REPORT OF CEMENT TESTS

WADDELL & HARRINGTON
CONSULTING ENGINEERS
Kansas City, Mo.

Testing Laboratory at..

....19......

....Inspector

Tests Made for.......................... Brand..........................

Cement to be Used for..

Car, Bin, or Load No...
Our No. Rwy. No. Initial or Name, etc.

Date Delivered...19..

Total Amount....Bbls. No. of Samples Taken.... Each Test Represents....Bbls.

Tensile Tests.................... Sample No..........................

Briquette No.	Date When Made	Time in Air	Age When Broken	Breaking Load	Remarks	Fineness Reqd. Tested
1						On No. 200, 75%....
2						On No. 100, 92%....
3						Soundness
4						Normal............
5						Accelerated.........
6						Time of Setting
7						First Set.....Minutes
8						Hard Set....H....M.
9						Reqd. 30 Min. and 3 Hours

Tensile Tests.................... Sample No..........................

Briquette No.	Date When Made	Time In Air	Age When Broken	Breaking Load	Remarks	Fineness Reqd. Tested
1						On No. 200, 75%....
2						On No. 100, 92%....
3						Soundness
4						Normal............
5						Accelerated.........
6						Time of Setting
7						First Set....Minutes. Hard Set...H.....M.
8						Reqd. 30 Min. and 3 Hours
9						

Car No............... Accepted or Rejected............19..........

FIG. 61f

DAILY PROGRESS REPORT SHEET ON SUPERSTRUCTURE

NOTE.—Figures on this sheet merely approximate Sheet No. 3

Resident Engineer, fill in columns marked*

WADDELL & HARRINGTON

CONSULTING ENGINEERS

KANSAS CITY, MO.

DAILY PROGRESS REPORT ON SUPERSTRUCTURE OF

No....................

Name of Structure.................... Date..........................

Weather............. Temperature................ Stage of River...........

STEELWORK—ERECTION

Span No.	Weight in Pounds					Following Work In Progress Today*
	Total Estimated	Delivered Today *	In Place Last Report	Erected Today *	Total Riveted To Date *	
Viaduct						
Totals						

FIG. 61*f*—*Continued*

DAILY PROGRESS REPORT SHEET ON SUPERSTRUCTURE

Note.—Figures on this sheet merely approximate
Resident Engineer, fill in columns marked*

Sheet No. 3

MISCELLANEOUS MATERIALS AND WORK

Classification	Required	Delivered*	In Place Last Report	Placed Today*	In Place To Date	Remarks*
Cement Bbls.						
Sand Cu. Yds.						
Stone Cu. Yds.						
Reinforcing Metal, Lbs.						
Track Rails, etc. Lbs.						
Paving Sq. Yds.						
Timber, Untreated M.						
Timber, Creosoted M.						

CONTRACTOR'S FORCE*

No. Men	Plant	Worked at
	Supts., Clerks, Watchmen, etc.	
	Total Men	

ENGINEER'S STAFF*

Name	Hours	Worked at

Contractor.............................. .... Resident Engineer

FIG. 61g

DAILY PROGRESS REPORT SHEET FOR
REINFORCED CONCRETE STRUCTURES

NOTE—Figures on this sheet merely approximate — Sheet No. 8

Resident Engineer, fill in columns marked*

WADDELL & HARRINGTON
CONSULTING ENGINEERS
KANSAS CITY, MO.

DAILY PROGRESS REPORT ON

No.............

Name of Structure....................... Date..........................

Weather.................. Temperature..........

Quantities		Total Esti-mated	In Place Last Report	Placed* Today	Total in Place	Work in Progress Today*
Concrete in						
Abutments	cu. yds.					
" Piers	cu. yds.					
" Arches or Gird's	cu. yds.					
" Floor System	cu. yds.					
Pavement	sq. yds.					
Hand Rail	lin. ft.					

Materials		Amount Required	Total Used	Used Today*	Left on Hand*	Remarks
Cement	bbls.					
Sand	cu. yds.					
Stone	cu. yds.					
Reinforcing Metal	lbs.					
Form Lumber	M.					
Falsework	lin. ft.					

FOUNDATION EXCAVATIONS AND PIER SINKING

Piers—Nos.	1	2	3	4	5	6	7	
Final Elevation, cutting edge								
Settled today *								
Elevation today *								
LAND EXCAVATIONS AT								
Total Excavation Required ft.*								
Total last report ft.								
Excavated today (depth in ft.)*								

FIG. 61*g*—*Continued*

DAILY PROGRESS REPORT SHEET FOR

REINFORCED CONCRETE STRUCTURES

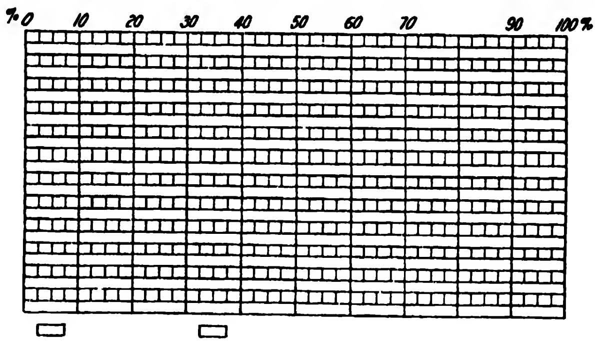
Note.—Figures on this sheet merely approximate Sheet No. 8

Resident Engineer, fill in columns marked*

CONTRACTOR'S FORCE*			ENGINEERING STAFF*		
No. Men	Plant	Worked at	Name	Hours	Worked at
....	....	....	....	......	....
....	....	....	....	......	....
....	....	....	....	......	....
....	....	....	....	......	....
	Supts., Clerks, Watchmen, etc.				
	Total Men				

Resident Engineer

FIG. 61*h*. Form for Percentage Report of Work.



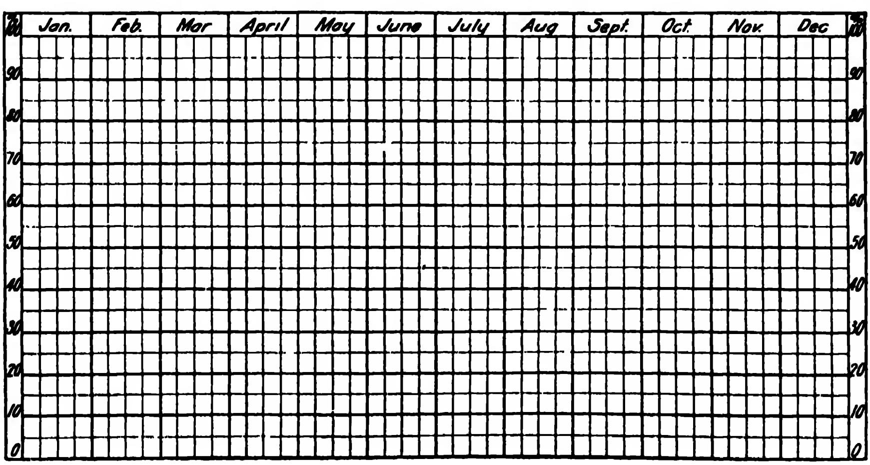


FIG. 61*i*

FORM FOR

SUMMARY OF CEMENT TESTS

WADDELL & HARRINGTON
CONSULTING ENGINEERS
KANSAS CITY, MO.

Testing Laboratory at....................................

....19....

..............................Inspector

Tests Made for......................... Brand..............................

Cement to be Used for..

Car, Bin, or Load No......, ...Date Delivered.....19....
Our No. Rwy. No. Initial or Name, etc.

Total Amount....Bbls. No. of Samples taken.... Each Test Represents.....Bbls.

FINENESS TESTS

Required to pass 200 sieve 92 per cent

Required to pass 100 sieve 75 per cent

Highest.........

Lowest..........

Average.........

SOUNDNESS TESTS

	Normal	Accelerated
No. of Tests O. K.	....	....
No. of Tests Failed	....	....

TENSILE TESTS

Required	1 day 150	7 day 350	28 day 500
Highest......	....	....	....
Lowest........	....	....	....
Average.......	....	....	....

SAND TENSILE TESTS

7 day 125	28 day 175
....	....
....	....
....	....

REMARKS..

....

....

....

....

Car No............. ACCEPTED OR REJECTED................19....

Averages given are for all the tests made

FIG. 61j

REPORT FORM FOR UNCLASSIFIED WORK

WADDELL & HARRINGTON

CONSULTING ENGINEERS

KANSAS CITY, MO.

For Unclassified Work done During month	Contract No..............
	Estimate No..............
ending....................	Bill No..................

UNCLASSIFIED WORK BILL

For work or materials which are not covered, or implied as covered, by the plans and specifications, under any price in the Contract.

By (Contractor)...

For (Purchaser)...

On (Job)..

COPY OF ORDER FROM ENGINEER

WADDELL & HARRINGTON By....................

ITEMIZED BILL

Total Amount Due....................

Approved: WADDELL & HARRINGTON By.........................
Resident Engineer

Bills for Unclassified Work are to be rendered monthly and included in the regular estimate.

One copy of this bill to be pasted to each copy of estimate.

The receipted vouchers for all items of this bill are to be sent to the main office. The Contractor is to prepare the bill with all copies desired, on this form, which will be furnished by the Resident Engineer.

FIG. 61*k*

MONTHLY STATEMENT FORM FOR COST CONTRACTS

WADDELL & HARRINGTON
CONSULTING ENGINEERS
KANSAS CITY, MO.

For...

....

Statement of work done by...

During month of................19....   Statement No...................

Items Bill No.	Expenditures During Month	Plus per Cent as Applicable	Amount Paid Directly by Owner	Difference
		Amount due by	this statement	

REMARKS:

We certify that this statement is correct
WADDELL & HARRINGTON
Consulting Engineers

By...................................Resident Engineer

CHAPTER LXII

ERECTION AND FALSEWORK

VARIOUS methods for erecting bridges have been developed to fit the different types of structures and the diverse conditions prevailing at the bridge sites. These methods may conveniently be grouped in two general classes, viz.:

First, erection with falsework; and second, erection without falsework.

The choice between these two methods will depend on the type of structure and the conditions at the bridge site. As a help in making such a choice for any particular case, the salient features of each method will be briefly set forth. The several types of bridge spans that the erector may be called upon to build are as follows:

1. Masonry arches.
2. Concrete girders and arches, both plain and reinforced.
3. Steel girders.
4. Viaducts and elevated railroads.
5. Truss spans.
6. Movable spans.
7. Suspension bridges.

Where a span is composed of numerous members that have to be assembled in final position, such as trusses, it is usually best and most economical to employ falsework, if the conditions at the site permit. Likewise, masonry and concrete arches, which require continuous support, are constructed on falsework, or centres, as the same is frequently termed. Those conditions at site favorable to the building of falsework are a river bed that will permit the driving of piles, an interval between floods sufficient to allow of the span or spans being assembled, riveted up, and swung, freedom from interference by river navigation, and the absence of deep water, swift current, drift-wood, and ice.

For single-track truss-spans, where no passing trains have to be provided for, it is customary to use falsework consisting of four-pile bents driven at intervals to correspond with the panel points of the truss. If a traveller is to be employed in erection, these bents are made wide enough to permit the placing at each end of a pair of 8″ × 16″ stringers outside of the span in order to support the rails on which the traveller runs. For shorter spans, where a derrick car will handle the material satisfactorily, the bents need be wide enough to carry only the two trusses. If the piles are sufficiently long to reach to the top of the falsework, they are capped with 12″ × 12″ timbers and sway-braced with 4″ × 8″ planks. In case

the said piles are too short so to reach, they are capped, and a framed bent is erected on top. Horizontal 6″ × 8″ timbers, running longitudinally, are used to tie the bents together and to give additional stiffness, when the height of the bents exceeds twice their width. For falsework on dry land or hard bottom, framed bents resting on mud sills may be constructed. The posts are usually 12″ × 12″ timbers with the outside pieces battered to give additional stability. Caps, sways, and longitudinal wales correspond to those in pile bents.

Should provision have to be made for carrying trains on a single-track bridge during erection, six piles or posts are used for each bent. Adequate longitudinal bracing similar to that required for timber trestles will have to be provided, in order to resist the thrust of braked trains. For the designing of falsework, the reader is referred to Chapter XXXV on "Wooden Bridges and Trestles," where he will find all the intensities of working stresses and other necessary information

It is usually desirable to erect the floor system first, and afterward the trusses; but occasionally it is best to erect the trusses first. This question is discussed quite fully by Mr. Reichmann on page 335. All truss connections are to be riveted up as soon as possible after the truss members are erected, in order that the span may be self-supporting in case the falsework is washed out.

For spans over 250 feet in length, erection is best carried on by means of a traveller. This is essentially a frame-work in the shape of an inverted U, supported on at least four rollers or wheels that rest on rails laid along the stringers of the falsework previously mentioned. This allows of the traveller's being readily moved along as erection progresses. At the top are convenient platforms for the workmen and tools; and on each side are hung several sets of blocks and tackle for raising the members of the truss. A hoisting engine is mounted on a lower platform for operating the tackle. Frequently swinging booms are placed at the forward corners so that they can be handled like a derrick. In large cantilever bridges it is practicable to employ one or two very small, comparatively speaking, travellers or "mules" riding on the top chords and picking up the material for erection from cars on the deck below. For spans under 250 feet and for trestles and elevated railroads, the traveller may be dispensed with and a derrick car or locomotive crane used for raising the parts into place.

The falsework, or centering, for masonry and concrete arches is more complicated than that required for truss spans, because the curved form of the arch necessitates special construction, and because the loads are distributed along the span length instead of being concentrated at panel points, as in trusses. This latter calls for continuous support, so that lagging and beams are necessary to transfer the load to the columns or bearings. Furthermore, the centering must be braced in order to resist the distortions produced by partial or unsymmetrical loadings. Set-

tlement of the supports is to be avoided as much as possible. Centering is sometimes built on top of temporary trusses, but in such cases provision must be made to offset the deflection of such trusses. Further provision must be made for a gradual lowering of these centres so as to bring every part of the arch into action at the same time. This is readily accomplished by using wedges under the centres, which wedges can be gradually loosened at all the supports. Sand-jacks are also frequently employed for the same purpose.

Where conditions do not admit of falseworks being constructed, truss-spans may be erected on barges at some distance, if need be, from the site

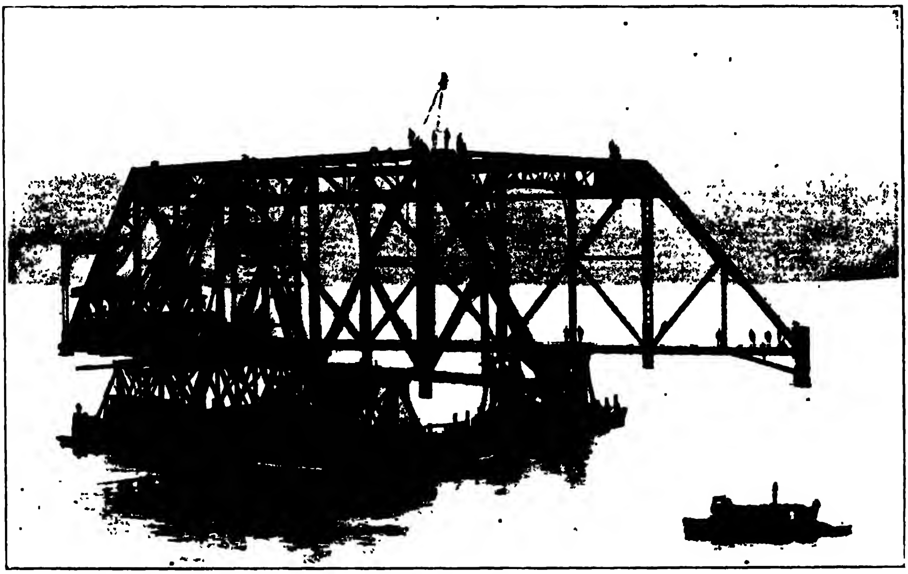


FIG. 62*a*. Floating the Spread Span of the Fraser River Bridge into Place.

and then floated into place and lowered onto the piers. This lowering is accomplished by means of jacks or by taking on water ballast. This method was adopted for the spread span of the author's bridge over the Fraser River at New Westminster, B. C. In that instance a depth of water of 80 feet and a reversing current of five miles per hour were encountered. The spread span, which was about 232 feet long and 136 feet wide at the wide end, while the narrow end was of the ordinary width of 19 feet, was erected on three barges placed in triangular formation, as shown in Fig. 62*a*. These were then floated into proper place, water ballast was admitted, and the span was thus lowered into final position on its piers. A detailed description, setting forth some of the unique features of the work, is given in the *Engineering Record*, Vol. 50, pages 192 to 194 inclusive.

Where it is not practicable to build falsework nor to erect the span on barges and float it into place, the structure can be erected by the

cantilever method. In this case special provision must be made in designing the bridge to take care of the erection stresses resulting from the temporary and unusual loading. A good example, and one of the earliest of this method of erection, is that of the Kentucky River High Bridge for the Cincinnati, New Orleans, and Texas Pacific Railway, twenty-one miles south of Lexington, Ky. The semi-cantilevering method of erecting simple spans was first proposed by the author over a quarter of a century ago, and has lately been used by him on several

FIG. 62b. Cantilever Erection of the Canadian Northern Pacific Railway Bridge over the Fraser River near Lytton, B. C.

bridges for the Canadian Northern Pacific Railway Company over the Fraser and the Thompson rivers in British Columbia. Here the swift current and hard bottom prevented the use of falsework in the main channels of both rivers. In the Fraser River bridge the centre span, which was 290 feet long, was erected from both ends by cantilevering out from each adjacent span; but for one of the Thompson River bridges, work could proceed from only one end, so that it was necessary to erect several contiguous spans by cantilevering the full span-length of 128 feet. Fig. 25*g* gives a view of the Fraser River bridge during the operation of semi-cantilevering.

Trussed arches are often erected by the cantilever method. One of the early examples of this was the erection of the Niagara Arch, described in *Engineering News*, Vol. 37, page 252. A later example is the Crooked River Bridge for the Oregon Trunk Railway, described in *Engineering News*, Vol. 69, page 549.

The author's 425′ arch span near Cisco over the Fraser River was erected by cantilevering out the two halves till they met at the middle,

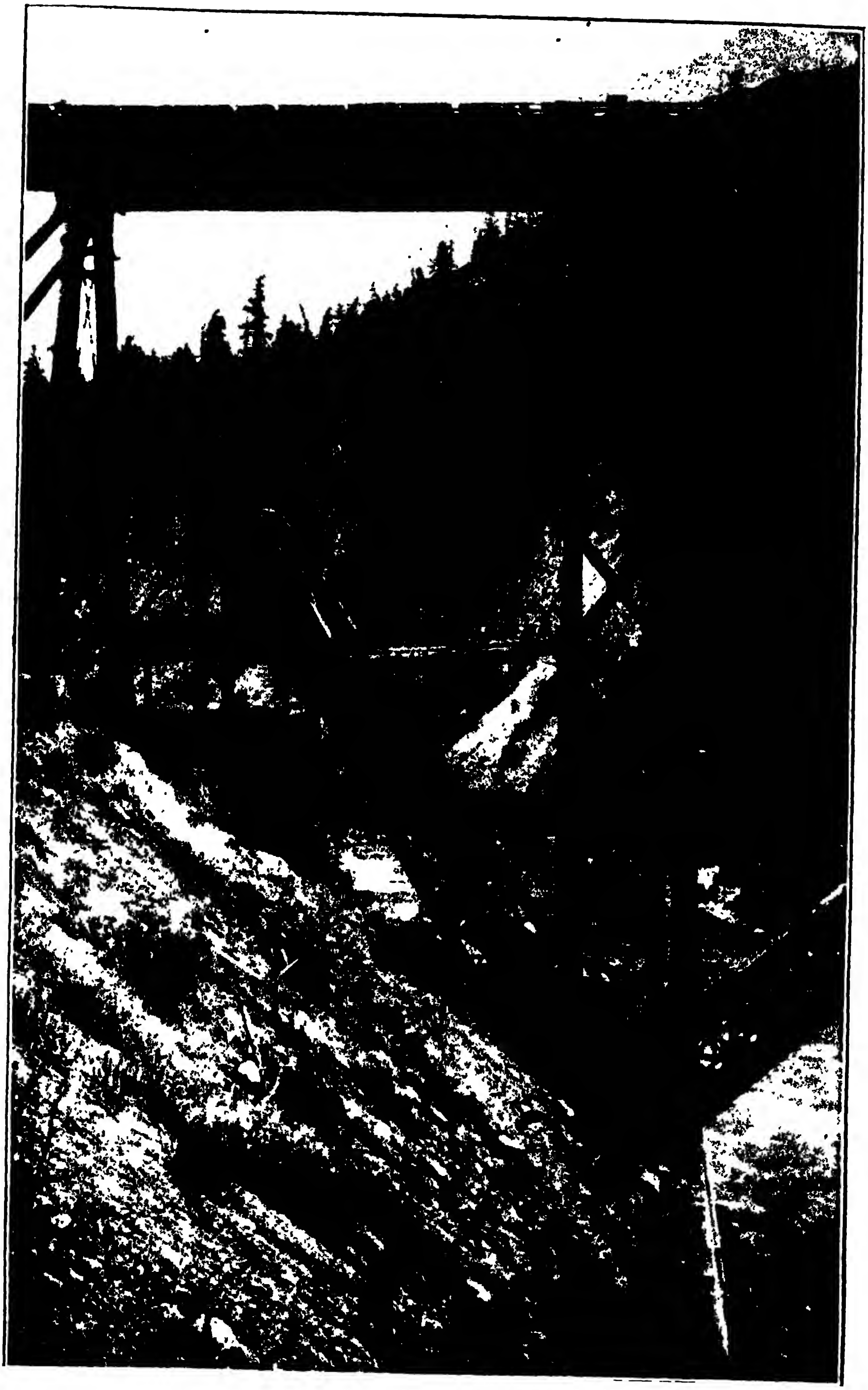


FIG. 62c. Counterweight for Anchoring, During Erection, the South Half of the Arch Span of the Canadian Northern Pacific Railway Bridge over the Fraser River.

as shown in Fig. 62*b*. At one end the anchor rods were nearly horizontal and were attached to the solid rock of a precipitous bluff, while at the other end they were inclined and attached to a pair of heavy steel booms and a massive suspended anchorage, as shown in the photograph. The size of the adjusting toggle can be realized from the picture, because there are several men standing inside of it. A larger view of it is given in Fig. 62*c*.

In some cases it is possible to use several intermediate supports in conjunction with the cantilever method, as was employed in the erection of the Bellows Falls Arch, described in Volume LXI of the *Transactions* of the American Society of Civil Engineers.

Another type of structure not requiring falsework is the girder span. This is usually set in place by means of a gallows frame, gin pole, derrick car, or locomotive crane.

Another method of erection, not often adopted, however, is that of launching the span endwise into place after it has been assembled near its final position. This is accomplished sometimes by building a temporary projecting truss to the end of the permanent span and then moving the combined structure forward on rollers until the permanent span reaches the desired position, when it is lowered to the piers. This method has been frequently used in Europe for small spans. An instance of it is the Jean François Lepin Bridge over the Northern Railway in Paris. The main span was 144 feet and weighed nearly 445 tons, while the temporary projecting framework was nearly 88 feet long and weighed only 56 tons. An illustrated account of this bridge and of its erection is to be found in the *Engineering Record*, Vol. XXXVII, page 449. A further instance of launching a span by the combined means of temporary suspension cables and a hinged boom is given in the *Transactions* of the Canadian Society of Civil Engineers, Vol. XVIII, page 350. In the case of the Reventazon River Bridge in Costa Rica, a four hundred foot span was launched on rollers by employing a temporary pier in mid-channel to support the structure until it had moved into place, after which it was jacked up and the rollers were taken out; and then it was lowered into position. See *Engineering Record*, Vol. 61, page 73.

The erection of a suspension bridge begins at the towers. After these are constructed, the strands composing the cables are anchored at one end, then carried up over the saddles on the tower and across the opening, by various means, to the next tower, which they pass over and then into the anchorage. A moving platform or scaffold is swung from the cable so that workmen may wrap it with coils of wire for its protection or place clamps and suspenders in position for carrying the floor system. To these suspenders are hung the stiffening trusses, which are erected generally by starting at the end of the bridge and using a moving derrick with boom of sufficient length to reach one or two panels ahead.

The organization needed for carrying on a job of erection will, of

course, depend very much on the size and class of bridge that is being constructed. The erection of steel structures calls for a special type of skilled workmen. In the larger jobs it is usual to have a crew of erectors, another crew of riveters, and still another crew for pile driving. In addition to those special crews it is desirable to have a gang of men for handling material. In the smaller jobs this division of labor is not carried out so extensively.

The usual equipment comprises a pile driver with hoisting engine for falsework construction, a derrick car for erecting the smaller spans, and a traveller with one or two hoisting engines for the larger spans. Several push cars for convenient transportation of materials are needed. For riveting, a pneumatic outfit is best, as more rivets per gang per day can be driven, and as there will be fewer loose rivets to cut out and replace. Moreover, modern specifications for bridge erecting demand that pneumatic riveters be employed for field riveting. Forges will be required for heating the rivets. These should usually be operated by hand, as there is then less danger of burning the rivets; but for large rivets the use of oil forges, operated by compressed air, is necessary. If the pneumatic plant is not installed, sledges will be needed for hand riveting. Various small tools, wrenches, drift pins, reamers, connecting bolts, etc., will have to be provided.

The erection of reinforced-concrete bridges is quite fully treated on page 946 *et seq.*; and certain features of erection work are discussed in Chapters LXIII and LXV.

For further information on the subject of erection and falsework the reader is referred to such standard works on bridges as those of Johnson, Bryan, and Turneaure, and Merriman and Jacoby. Special mention should be made of the excellent illustrated chapter on "Adjusting and Erection Devices," in Prof. C. W. Hudson's book, "Deflections and Statically Indeterminate Stresses."

CHAPTER LXIII

MAINTENANCE OF TRAFFIC

THE problem of maintaining traffic on an existing line while replacing an old bridge with a new one becomes in some cases a very difficult matter, and may involve such serious complications as even to affect the design of the new structure. Various methods of traffic maintenance have been employed, each one having some special advantage for different sets of conditions. As a guide to a choice of methods to adopt, the main features of each are herewith set forth.

Where trains are more than a half hour apart and piles can readily be driven beneath or through the structure, it will be cheapest to erect falsework under the old superstructure, remove the latter piece by piece, erect the new span on the same supports, and then demolish the falsework. This timber construction must be designed to carry the live load as well as the weight of the span; and it should have adequate longitudinal bracing in order to withstand safely the thrust from braked trains In Chapter LXII will be found a description of the different types of falsework suitable for various conditions. This method increases in advantage directly as the interval between trains.

For those cases where the service is more frequent than one train each half hour during a considerable portion of the day, it will be found best to build, if possible, a by-pass or run-around. This is usually a pile or timber trestle. If river traffic has also to be maintained, it will be necessary to have a movable span in the said trestle in order to permit of the passage of boats. This movable span may be a pair of girders arranged to act as a lift span, or a bascule, or in some cases the span may be pivoted at one end on the corner and have the other end supported by a barge when in operation.

In rare cases the existing superstructure may be utilized to support the new span and to carry also a limited train service, under which circumstances the falsework can be dispensed with; but it will then be necessary that the perpendicular distance between central planes of trusses of the new span exceed that of the old one sufficiently to permit of the new construction surrounding that which is to be replaced. This method is seldom employed, because nearly all renewals are due to insufficient strength of the old structures, which generally have all they can do to carry their own weight in addition to the live load without assuming to sustain the weight of the new steel. However, certain conditions make it necessary to adopt this method. Such was the case at Kenova, W. Va.,

where the Norfolk and Western Railway had to renew its bridge across the Ohio River. It was important that every precaution should be taken to prevent accidents during reconstruction, as the nearest river crossing above Kenova was at Point Pleasant, 60 miles away, and the next nearest crossing was at Cincinnati, 150 miles down stream. The variation in water level amounted to some 70 feet between flood and low-water elevations, and provision had to be made for river navigation at all times during reconstruction. On account of these strenuous conditions and because of the very heavy traffic, the contract stipulated that no falsework should be placed in the river. The method finally adopted was to construct falsework only under the stringers of the end spans, which, at ordinary stages of the river, were over dry ground, then to disconnect the stringers from the floor-beams, leaving the falsework to carry the old stringers, the old track, and the live load. The new floor-beams were then suspended from the old ones by rods, and the new spans were built up around the old ones on brackets attached to the ends of the new floor-beams in their suspended position. After the new trusses were swung, the old spans were blocked up on them and dismantled, the brackets were taken off the new floor-beams, the latter were hoisted to proper elevation and riveted into the posts, the new stringers were inserted and attached, the new lateral bracing was put in, and the track was laid. Of course, there was for each span a short interval when it was incapable of withstanding much wind pressure because of its lack of lateral bracing. By choosing quiet weather and working quickly it was possible to reduce this danger to a minimum.

The spans adjacent to the end ones were erected by cantilevering out their full length from the finished spans, building around the existing structure and depending upon it for lateral resistance, then making the new trusses support the old span, removing the latter piecemeal, and putting in the new floor system and new lateral system.

Finally, the long central span was erected in two parts by cantilevering from the two adjacent finished spans until the half trusses met at the centre, when they were connected and swung, and then they were made to support the old span while it was being demolished and while the new floor system and new lower lateral system were being inserted. An account of this reconstruction is given in the January, 1915, *Proceedings* of the American Society of Civil Engineers.

The renewal of an old bridge often calls for the construction of new substructure. If a slight change in alignment of track can be made, and if the conditions are favorable for the building of falsework, it will be found economical to erect the new spans on falsework alongside of the old bridge and extended underneath the latter for the purpose of demolition. When the erection is completed, a cutting and shifting of the tracks can readily be made, and then the traffic can be transferred to the new structure. In this way practically all interruption thereof will be

avoided. If the old track has curves near the bridge a change in alignment can usually be effected; but if a long tangent exists, it may not be allowable to do the shifting proposed.

Where the water is too deep or the current is too swift for falsework to be constructed and maintained safely, the method of erecting the new spans on barges and floating them to position may be adopted with advantage. In this case the spans are erected on falsework near the shore, and then two or more barges—the number depending on their size and the span length—are partially filled with water and run in under the span between the falsework bents. Then blocking is placed so that the load is transferred from the falsework to the barges when the water is pumped therefrom. In the meantime barges have been run in under the old spans, and blocking has been placed so that the load is taken off the piers and transferred to the barges. The barges carrying the new span are then brought near to their position at the site; and as the old span moves out the new span moves in. When in position and guyed, it is lowered into place either by the removal of some of the blocking or by flooding the barges. After landing the new span on the piers, the rails are connected and traffic is resumed. This method under the best of conditions consumes several hours of time and interferes with traffic to a corresponding extent. It also requires considerable equipment of barges and tug boats. It was used in reconstructing the Coteau Bridge across the St. Lawrence River by the Grand Trunk Railway Company. A detailed account of the work will be found in the *Engineering Record*, Vol. 62, page 628. This bridge was out of service only a few hours for each span.

It seems hardly necessary to suggest that if the bridge is located where rising and falling of the water level occur daily from tidal action, the barges can be run under the new span at low tide, then the span can be lifted off its bearings at half tide and floated into position at highest tide; and finally the barges may be removed as the tide falls, thus obviating the necessity of flooding them, pumping them out, and flooding them again.

Under some conditions where falsework cannot be constructed and when there are several duplicate spans to be replaced, falsework is built on one set of barges for one new span and upon another set for one old span; then when a span is torn down and replaced, the barges with their superimposed falsework are moved ahead to the next span, and the operations just described are repeated. This method is not adapted for much fluctuation in water level; but small changes of a foot or so can be taken care of by means of water ballast, which can be let in or pumped out as the case may require.

Another method of replacing an old span, where train service is frequent and interruption of traffic is not allowable, is that of erecting the new span alongside of the old one, supporting the ends on special tracks

and rollers, and rolling it into position as the old span is rolled out. In this case the usual procedure is to extend the old piers on one side of the bridge by specially constructed falsework sufficiently strong to carry the weight of the span, then raise the old span and place a double set of rails under the shoes, with rollers between the tiers of rails. By means of adequate block and tackle and a hoisting engine or locomotive at each end of the span, the old span is moved out of place and the new one moved in, the rails and the rollers are removed, and the span is lowered to a bearing on the piers. One difficulty encountered in this method is the picking up of the span without bringing excessive concentrations on the end floor-beams and the lower chord. Usually there is very little working room around the shoe for placing and operating the jacks. Various expedients in the way of suspenders and loading beams have been devised in order to carry the load at the end pins. A good example of this arrangement of loading beams and suspenders is that used in the reconstruction of the Steubenville Bridge over the Ohio River for the Pittsburg Division of the Pittsburg, Cincinnati, Chicago and St. Louis Railway. In this case the spans were exceedingly heavy; and, therefore, unusual care had to be taken. Two of the spans weighed 3,100,000 lbs. gross each, and another one weighed 2,520,000 lbs. gross. The time consumed in moving each of the heavier spans was forty-three minutes. Within this interval the tracks were disconnected, the weight of the old spans was transferred from the piers to the rolling carriages, the old and the new spans were moved 25 feet, the new spans were lowered to their permanent position on the piers, and the tracks were re-connected. The time consumed in moving the lighter span was only seventeen minutes. A good account of this work will be found in the *Engineering Record*, Vol. 62, page 596.

The author has had occasion on some of his work to move spans longitudinally from temporary piers to permanent piers without interrupting traffic. In case of the Rio Blanco Bridge on the Vera Cruz and Pacific Railway in Mexico, a truss span weighing 240 tons had to be moved about twenty feet. The span was erected on timber piers, as there was not sufficient time to build permanent substructure and then erect the metal before the high-water period. This expedient gave the railroad company a crossing over a deep and swift river that could not otherwise have been had during the flood season, which lasted several months. When the river had again subsided to a normal dry-season flow, the permanent piers were constructed, then the spaces between these and the temporary piers were filled with substantial falsework sufficiently strong to carry one end of the span. On top of the deck were placed railroad rails close together and having a slight pitch downward toward the new piers. These were greased, slipped under the shoes of the span, and extended to the new piers, thus forming ways for the span to slide upon. Blocks and tackle were rigged and attached to the end of the span, and a hoisting engine was used for the operation. It was found that this

was not sufficient to start the mass to moving; consequently jacks were set up in inclined positions under the end floor-beams. Then the slack was taken out of the tackle, and the jacks were operated simultaneously, thus giving a "kick" to the span, after which the engine was able to keep it in motion. The entire movement occupied about half an hour after the actual start was made.

Another instance of moving spans longitudinally is that of the Missouri Pacific Railroad Bridge across the Kaw River at Kansas City. In this instance three double-track spans had to be raised six and a half feet, moved laterally about twenty-five feet, and carried longitudinally one hundred and twenty-five feet. For the lateral movement pile falsework was constructed so as to support the structure while passing to its new position. Two tiers of rails with two-inch steel rollers between were placed under each shoe. Blocks and tackle were placed at each end of the several spans, and hoisting engines were used to operate them. After the lateral movement was accomplished, special trucks built of timber, each having six standard car wheels with their axles and journal boxes, were distributed under the spans, so as to spread the load as much as possible. These trucks rolled on rails placed upon the falsework underneath the bridge. The movement of the mass was started by a combined stressing of the tackle, operating jacks set on inclines at various points under the shoes, and pushing with a locomotive by means of a strut against the end floor-beam. The entire movement occupied about three minutes. A good description of this work, with illustrations, is to be found in *Engineering News*, Vol. 70, page 54.

In either double-tracking an existing single-track bridge or replacing it by another single-track one, where plate girders of the same length are adopted to replace old through truss spans, and where it is desirable to avoid building falsework, it is a good plan to erect at the shore end of the structure several gallows frames at convenient intervals, depending on the length of the said girders, and to place on the top chords of each truss span several heavy cross beams or "jiggers." If any of the girders are to be placed outside of the old trusses, these jiggers should cantilever over the chords a sufficient distance to handle them easily. Two sets of blocks and tackle are then to be rigged up to each gallows frame and each jigger; and the girder is to be picked up by two adjacent tackles, and attached to the next forward tackle, then a stress is to be put upon the latter. If the girder goes inside of the truss, the floor system must be cut loose from the trusses and gotten out of the way. As the stress on the forward tackle is increased, a horizontal movement is to be given to the girder, and then the head supporting-tackle should be eased off gradually, detached from the front end of the girder, and reattached to the rear end thereof. A stress is then to be taken on the last mentioned tackle and the rear tackle released slowly. This will permit the girder to swing forward. This operation is to be repeated with

the next set of tackle until the girder has reached the proper position for lowering on the piers. After the girders are placed and the floor system is completed, it is usually an easy matter to dismantle the old trusses with a derrick car on the track. A good illustration of this method was the replacing of truss spans on the Auburn Division of the Lehigh Valley Railroad at Weedsport, N. Y., an account of which is given in the *Engineering Record*, Vol. 60, page 290. A somewhat similar method was that adopted by the Duluth, South Shore, and Atlantic Railway Company on its line at the Bad River crossing near Shilo, Wis., where a 150-foot Howe truss span was replaced by a 121-foot plate girder span. The latter was assembled on two flat cars, riveted up completely, and then hauled out on the truss span. One end was picked up by a gallows frame, previously erected at the shore end of the Howe-truss span, and the other end was supported by a derrick car. After lifting the span off the cars, which were then run back to shore, the deck members of the truss span were removed, one piece at a time, and dropped into the river below, from which they were afterward fished out. The girder span was then lowered to position between the old trusses, which were later removed at convenience. The time occupied in moving the span out from shore, setting it in place, and connecting up the track was five hours.

Where a double-track structure of reinforced concrete girders or arches is to displace an old bridge, it is usually possible to build a longitudinal half of the entire concrete construction while traffic is being taken care of on a single track of the old bridge. When this first portion of the concrete work is finished, the track is shifted to its deck, and the old structure is demolished; after which the remainder of the concrete is placed and the bridge is completed. An example of this is the renewal of the Gwynns Falls Bridge in the city of Baltimore for the Philadelphia, Baltimore, and Washington Railroad. In this case traffic was maintained on the old structure while the first half of the new bridge was built. When this was finished, tracks were laid over it, and the traffic was diverted from the old bridge, which was then dismantled. This permitted the finishing of the remaining half of the concrete work without interrupting traffic.

Many variations and combinations of the foregoing described methods are to be met with in practice. Each case had to be studied by itself and the method of construction adjusted to suit its peculiarities.

In all this work precautions must be taken to carry out the regulations of the operating department of the railroad in regard to lights, signals, and flagging trains.

In preparing this chapter the author received many valuable suggestions from L. S. Stewart, Esq., President, and H. K. Seltzer, Esq., C. E., Vice-President of the Union Bridge and Construction Company of Kansas City, one of the best known bridge building companies of America, for which help he desires to express here his hearty thanks.

CHAPTER LXIV

BRIDGE EXAMINATION

The examination of old structures constitutes quite a percentage of the practice of some bridge specialists. Although it is not as interesting or satisfactory professional work as the designing of new bridges, it is just as important; for upon the skill, experience, thoroughness, and integrity of the engineer who examines and reports upon the condition of railway and highway bridges depends the safety of the traveling public. No one except an experienced bridge engineer should be permitted to examine and report on such structures, because an inexperienced man is apt to overlook many important matters when making the examination; and often it requires rare judgment to determine whether a structure should be passed as sufficiently strong, ordered repaired, or condemned to be removed.

The objects of bridge inspection are as follows:

A. To discover weaknesses or defects and how serious they are.

B. To ascertain the amount of deterioration of the structure, and, if possible, its rate, in order to figure upon its probable remaining length of life.

C. To determine the safety of the structure under all probable conditions of loading.

D. To decide upon whether there is any necessity for repairs, reinforcements, or renewals, what these should be, and their urgency.

E. To settle as to what should be done in order to carry the live loads safely while repairs or renewals are in progress.

The frequency with which bridge inspections should be made depends upon a variety of conditions, among which may be mentioned the character of the structure, its location, its strength, and its general physical condition. Bridges built of late years on scientific principles and under thorough inspection may need but a single inspection per annum, while some old and unscientifically designed ones may require to be gone over carefully every few weeks, or in extreme cases every few days.

For railroad bridges a special committee of the American Railway Engineering Association recommends the following system of inspection:

"(1) Inspection by the regular section forces, daily, or as often as they inspect the track under their supervision. The object of this inspection is to discover any damage to the structure from fire, flood, derailments, or other accidents from traffic, or any displacement in the structure in whole or in part. This inspection, due to the lack of skill on the part of the section forces must necessarily be superficial, and

will rarely, if ever, do more than call attention to unsafe conditions arising from causes other than those of natural depreciation. No reports of such inspections need be made unless adverse conditions are discovered.

"(2) At periodic intervals of from one to six months there should be inspections by bridge foremen or others experienced in bridge repairs. These inspections should be more thorough than those of the section forces, and are intended to discover all the defects, arising from traffic, to which the bridge is subjected, and those due to natural depreciation or other cause. Reports of such inspections should be made to the one next in authority; preferably to the one most directly or primarily responsible for the safety of the structure.

"(3) Annual or semi-annual inspections are to be made by men experienced in the design and maintenance of bridges; preferably by those who are primarily responsible for their safe maintenance. The reports of these inspections should be filed, and in connection with an examination of office data they will determine the safety of the structures, and will be the basis for decisions as to repairs, reinforcements, or renewals.

"The inspections outlined in (1), (2) and (3) above must be considered as quite general. There will often be cases where much more frequent and thorough inspection than above outlined will be necessary, especially for structures which are carrying traffic much heavier than that for which they were designed, or which, by reason of poor design, age, or injury of any kind, have a reduced margin of safety. Because of inability to renew some bridges in time for changed traffic conditions, uncertainties as to revision work, lack of time for replacement after injury, or other reasons, it is occasionally necessary to keep in service structures which have not the usual margin of safety. The manner and frequency of the inspection necessary safely to maintain such structures must be determined separately for each individual case.

"Railway bridges are of timber, masonry, or metal, and occasionally of unusual design; men competent to inspect one kind are often incompetent to inspect other kinds, and, therefore, it may be necessary to limit an inspector to structures of a certain kind. It is sometimes desirable to have large and important or doubtful structures inspected by expert engineers."

This last remark of the committee's does not carry with it sufficient force; because it is highly advisable for every railroad company to have all its bridges examined and reported upon from time to time by an expert who is not regularly in its employ. He is likely to discover some important facts that have been overlooked by the regular employees of the road. Such occasional examinations to a certain extent serve as a partial protection to the company against excessive claims for damages due to bridge accidents; because, if it is shown that the company took the precaution to secure expert opinion concerning the safety of its bridges, any jury is likely to conclude that it did all in its power to avert the accident.

As long ago as 1887, in a discussion at the Annual Convention of the American Society of Civil Engineers upon the subject of "Inspection and Maintenance of Railway Structures," the author wrote as follows in answer to the question, "What is proper bridge inspection?" and, as he has had no occasion since to change his mind about any of the points therein covered, he has decided to reproduce here verbatim that part of his discussion. It reads thus:

"There are two kind of bridge inspection, viz.:

"A. Inspection of structures the dimensions of which are not on record.

"B. Inspection of structures the dimensions of which are on record.

The former is, of course, much more extensive and thorough than the latter. It should be made as follows or in some similar way:

"I. Measure systematically the main dimensions of the structure and the sections of all the principal members, recording them always in a certain manner, determined by experience to be the best, so that any particular data may be found immediately by inspecting the field notes, which, by the way, should be made in ink.

"II. Measure and record systematically the sizes of all parts in the neighborhood of each panel point and each connection of main members, showing number, spacing and diameter of rivets, the packing, including the distance of centre line of each piece from plane of symmetry, dimensions of eye-bar heads, thickness of bearings, and, in short, every dimension that could under any circumstances be required.

"III. Measure and record systematically all the details of main members between panel points or connections, for instance, sizes of lacing bars, stay plates, stiffening angles, etc.

"IV. Examine the structure carefully so as to find any faults in manufacture or design, such as loose or unequally stressed tension members, bad packing, omission of fillers, bad riveting, twisted or otherwise distorted members, inefficient bracing, loose connections, etc., also the various effects of wear, such as loose rivets, bent pins, rust, decayed timber, cracked castings, and defective masonry or other material at pedestals.

"V. Look to the efficiency of the floor system proper, viz.: the ties, rails, and guards, also to the means of protecting the structure from injury by fire, derailment, vibration, etc.

"VI. Examine thoroughly and make notes upon the substructure, giving the principal measurements, quality and condition of materials, etc. Describe the crossing of the stream or chasm, noting, if possible, high and low water, velocity of stream, and any other information that may be of use.

"VII. Note the effect upon the bridge of rapidly passing trains, measuring and recording, if thought necessary, the deflections.

"VIII. Note, if possible, the names of the designer and the manufacturer and the date of erection.

"IX. Record in the note-book the names of the members of the inspecting party, the date, and the time spent in making measurements.

"The inspection of structures the dimensions of which are on record should be made simply with the view of ascertaining the effect of wear upon the structure. The items are mentioned under the previous headings numbered IV, V, VI, and VII. Before making such an inspection, the inspector should read carefully the notes of the previous inspections, and determine where to look specially for the effects of wear."

When one is examining a bridge of which the working drawings are at hand, he should check the structure at a number of places, in order to make sure that it was really built in accordance with the said drawings; and if it be found that in any particular there is a lack of agreement, the drawings should be discarded entirely, and the structure should be examined and measured in exactly the same thorough manner as it would have to be were no drawings available.

The character of the material of which the bridge under examination was built is sometimes difficult to determine. Occasionally it is recorded

on the working drawings; but generally it can be found only in the specifications under which the bridge was built, and too often these cannot be located. Usually the date of erection and the name of the manufacturing company recorded on the structure will lead to securing the desired information—at any rate, they will determine whether the metal is wrought iron or steel, and, if the latter, whether it was manufactured by the Bessemer or the open-hearth process. As a last resort, one can take out a member and test it; but this is seldom done, mainly because of the trouble involved, but also because such a test would cover only a portion of the whole metal, which may have been purchased from several different rolling mills. In testing an old bridge the author does not often attempt to determine the character of the metal. If he knows it to be wrought iron, he assumes that it had an elastic limit of 25,000 pounds per square inch and an ultimate strength of 50,000 pounds per square inch, and if he knows it to be steel, he assumes instead 30,000 pounds and 60,000 pounds respectively.

One of the difficult things for an inspecting engineer to determine is the percentage of deterioration of metal by rust. It is usually easy to ascertain what were the original dimensions of any section; for rust does not attack metal uniformly; hence one can find places where the member is full sized, and then by measuring the section at the points of greatest deterioration he can determine the percentage of lost area. By obtaining such percentages at several places and striking an average thereof or by using the maximum, as his judgment may dictate, one can obtain a general percentage of deterioration to apply to the metal of the whole structure, or better yet to certain parts of it; for the deterioration will be different in the trusses, the floor system, and the lateral system. If a steel structure has been badly neglected and allowed to rust, it must be remembered that the rusting is by no means as serious as it looks, for the flakes that peel off are from five to eight times as thick as the metal which they destroyed and removed.

The inspector should be constantly on the lookout for injuries to the metal caused by blows from passing trains or falling objects, or by locomotive fumes or salt drippings from refrigerator cars.

The character of the workmanship on the metal can be determined only by eye; and it is generally customary for the inspecting engineer to assume that it is all right, unless he encounter some glaring evidence to the contrary.

The detection of loose rivets is done by a combination of three senses, viz.: sight, touch, and hearing. Of course, it is not necessary to tap with a rivet hammer all the rivets in a structure, for the experienced bridge engineer knows well where to examine for loose ones; and if he finds none after testing about twenty (20) per cent of all the rivets in any group, he will conclude that there are none in the remainder of the said group and will note accordingly.

In testing old timbers for soundness, they should be bored with an augur in numerous places, the number of holes depending upon the conditions ascertained. All such test holes should be filled with tight wooden plugs so as to prevent the entrance of moisture and the consequent rotting of the timber.

The condition of the flooring pavements, track, hand-rails, etc., should receive careful attention, and the open spaces in the floor over piers and abutments require special pains in examination; because trouble is likely to occur at such points, especially in old style bridges.

The soundness of old stone masonry is difficult to prove; but some idea of it may be obtained by making an attempt to probe the joints with small steel rods. If any great penetration is obtained, the masonry is faulty and will need attention. Concrete masonry is more easily inspected, as its defects are likely to be on the exterior.

Foundations should be examined for the effects of scour, and the lower parts of pier shafts for abrasion by ice and drift. If any piles are exposed, they should be inspected carefully for deterioration.

When examining a series of bridges for a railroad system, the author has made a practice of requesting the use of a train, consisting of a heavy locomotive, a heavily loaded freight-car or two, and a caboose. If the inspecting party is to be several days on the work, and if conveniences for board and lodging along the line are not available, it is well to attach a private car to the end of the train. Quite often the general manager, the superintendent, or the chief engineer will join the inspecting party and accommodate it by the loan of his private car. After each bridge is measured and inspected, it is to be tested for deflection by placing a deflectometer upon it, preferably at mid-span, attached by a wire to a weight resting on the river bed, and measuring the actual span deflections (exaggerated twofold on the recording paper), first with the train at rest in the position which will produce the greatest deflection, and then at different velocities gradually increased until either the attainable limit of speed of train is reached or prudence forbids running any further risk of wrecking the structure. The ratio of any dynamic deflection to the static deflection minus unity will give the coefficient of impact for the span as a whole under the train velocity in question. That velocity has to be determined approximately by noting the time occupied by the train in passing a measured stretch of track, or by the trained judgment of the engine driver or train conductor.

In making the computations for actual intensities of working stresses, one should assume a live load of the usual type adjusted for the actual loads that either pass over the line ordinarily or those that are likely to pass over it in the immediate future. To the static stresses calculated from this assumed live load are to be added the usual allowances for impact and the dead load stresses computed from an assumed dead load of structure. Generally an experienced bridge engineer can tell with suf-

ficient accuracy from his office tables and diagrams what the approximate dead load should be; but, if not, the computer must figure the actual dead load from the recorded measurements of members. Sometimes the original stress sheet from which the bridge was manufactured is available; and in that case the assumed dead load recorded on it will suffice, as no extreme accuracy in this matter is necessary.

The computed component stresses are written on a stress-diagram and the totals are summed, then the area of each main member, properly reduced for rust deterioration, is written along its axial line, and the resulting intensity is figured and recorded on the sheet. This actual intensity is then compared with the permissible intensity of the engineer's specifications for designing new bridges, and its excess is written on the diagram. These excesses, together with the recorded notes of the inspection, constitute the criterion for passing or rejecting the structure. The author's general rule is to condemn or order strengthened any truss bridge or open-webbed girder in which the excess exceeds fifty (50) per cent, and any plate-girder span where it is greater than sixty (60) per cent. Of course, one has to be influenced more or less by the signs of wear that he finds. If no loose rivets are in evidence, one can raise slightly the excess limit; but if the reverse is the case, it may have to be materially reduced. The addition of a few rivets to some of the connections, provided there be room to put them in, will sometimes correct the worst overstresses in the structure and permit of its being retained in service for several years longer. One should be chary about ordering removed any bridge that can be made serviceable at moderate expense; but, on the other hand, he should take no chances by risking the lives of the travelling public through an endeavor to save money for his clients. Above all things, though, he should let no latent hope of being retained to design a new structure for the crossing influence him to condemn to removal any bridge that might legitimately be strengthened and used.

The question of how much it is economic to spend in repairing an old structure is treated in Chapter LXV. It should receive for each bridge examined thorough consideration by the inspecting engineer before reporting to his principal; and his report should set forth clearly the results of his findings on this important matter. The report should state the engineer's opinion as to the probable safe life of each bridge that he examines, upon the basis, first, of the existing traffic, and, second, on that of possible or probable future increases in the live loads to be carried.

The question often arises as to what an expert bridge engineer should charge for examining and reporting upon bridges. The author's practice in the case of small structures is to charge one hundred dollars per day and all expenses, counting in all the time spent in traveling, examining, and reporting; but when retained by a railroad company to examine a large number of bridges on its line, and when he is provided with a special

train and all the necessary facilities, he makes an average charge of thirty (30) cents per lineal foot of structure examined, no reduction being allowed for duplicate spans nor for any other condition. These figures are moderate, considering the importance of the work done and the responsibility assumed by the inspecting engineer.

Just as the manuscript of this book was about to go to the printer, Messrs. Hildreth & Co. very kindly sent the author a copy of their standard instructions to assistants in relation to the examination of existing railway bridges; and as these are very complete in detail, he has decided to append them to this chapter, not only because of their thoroughness but also because it is well for the reader to consider the subject from more than a single point of view. The said instructions read as follows:

"Inspection of Existing Railway Bridges

"General. Notes should be full and well illustrated by photographs and sketches. Each span must be covered separately and systematically by panels in consecutive order, with the direction to the nearest important station indicated at the first panel point.

"Note character of approaches, grade, and alignment of track. Note size and condition of ties, rails, and rail joints, particularly on bridge and adjacent to bridge—on both sides for 500 feet.

"Foundations. Note any evidences of settlement, crack, or movement, particularly any movement tending to 'pinch' the bridge. Make accurate measurements and establish bench marks and reference points so that further movement may be determined.

"Anchorage. Note condition of anchor bolts and nuts and whether there is ample space for expansion and contraction. There should be allowed $1\frac{5}{8}''$ per 100 feet for range of temperature of 150 degrees, or $^1/_{700}$ of the span. All bearings, particularly roller bearings, must be clear of rubbish. Note any tendency to uplift or overturn bases.

"Line. Check line of structure with transit, including sighting bottom and top chords. Check line of tower columns for bending, and sight all important members of each span by eye.

"Camber. Test with surveyor's level, or for short spans with cord or piano wire stretched between the supports.

"Deflection. Test deflection under maximum load available (preferably two heaviest engines in use, coupled) with surveyor's level, or for short spans with cord or piano wire stretched between the supports, or wire with weight and spring balance at the centre.

"Rivets. Test all rivets, particularly field connections, with special care for floor connections. In plate girders test carefully rivets near ends and those of lateral and sway connections. Look for rust streaks below rivets, indicating looseness.

"Pins. Look for evidences of wear and bending, particularly at hip verticals. Note movement of pin nuts.

"Bearings. Examine all bearings of compression members. Examine stringer ends which, if on shelf angles or top flange angles of floor-beams, should have brackets or web stiffeners beneath the stringer bearing.

"Bracing. Shake all braces and note any which are loose or bent. See that adjustable rods are taking sufficient and uniform tension.

"Counters. Shake all counters and examine carefully to determine that they

do not take too great tension; they should be just tight under dead load and uniformly stiff under live load.

"EYE-BARS. Shake all eye-bars; they should be under uniform stiff tension.

"RUST. Examine entire structure for rust, particularly the details near masonry. Note greatest reduction of cross section therefrom in each member.

"DEFECTS. Examine entire structure thoroughly for evidence of defects of material or workmanship. Note cracks, openings, bending, distortion, or movement of any kind.

"VIBRATION. During the passage of a regular train at usual maximum speed, note vibration from position on top chord of through bridge or on bottom chord of deck bridge.

"If record plans do not exist:

"PLANS must be made up including map, showing topography and profile 500′ from each end. Sketch any bend in stream.

"MASONRY. Measure and sketch piers and abutments—elevation, section, and top plan, latter showing size and location of bridge seats, and the clear span under coping and between back walls. Sketch accurately the upper five courses of masonry, showing joints. Describe quality and condition of masonry. In case of movement, and when so directed, dig test pits adjacent to abutments and make borings close to abutments and piers to determine character of soil and its probable bearing capacity.

"SUPERSTRUCTURE. All data must be secured in order to prepare plans as for a new bridge—main dimensions, details, clearances, sections of material, rivet spacing, etc. A set of plans of a new bridge can with advantage be used as a guide, indicating the information required.

"For the above described examinations the following instruments, etc., are needed:

"Surveyor's level and transit (or combined instrument), 100-foot steel tape, 200 feet of stout linen cord, 100 feet of piano wire, spring balance, plumb bob, 4 to 6 foot rule, hammer for testing rivets, steel scale, large and small calipers, chalk or paint."

CHAPTER LXV

RECONSTRUCTION, MAINTENANCE, AND REPAIR OF EXISTING BRIDGES

Experience shows that any metal bridge of imperfect design materially overloaded or ineffectively painted deteriorates with age and use, and that there is a limit to the time during which it can perform its function satisfactorily and safely. The continual increase in live loads and also that of the speed of trains tend to hasten the day of its replacement. To prolong its life as much as possible calls for the skill of the bridge expert and requires regularity of attention in order to recognize the smaller defects and deteriorations as they develop and to remedy them before they become serious. This work is included under the term maintenance. Where some accident results in slight damage to the structure beyond the usual wear and tear, necessitating restoration on a more extensive scale than that of ordinary maintenance, the work is embraced under the head of repairs. There is no well-defined line between these two classes of operations; and it is difficult at times properly to classify such work.

Reconstruction may be considered to cover the more extensive repairs and replacements of certain portions of the structure whether necessitated by a serious accident, or by an accelerated deterioration, or by increase in loading. Neither is there a sharp distinction between repairs and reconstruction, but rather a merging of the two classifications. However, it is always well to attempt such a division in order to promote an adequate system of accounting.

Maintenance embraces preventive work. The prevention of rusting by promptly painting either the entire span or the affected portions of it, the cleaning of dirt away from the shoes or bearing plates, the oiling of rollers, and the covering of floor-beams with boards, so that the brine-drippings from the refrigerator cars cannot strike the metal, are all examples of maintenance. Such prevention work, to be most effective, calls for frequent and regular inspections and a system of records that will enable the engineer in charge to know at all times the true condition of his structures without doing any guessing. Positive knowledge is needed as a basis for efficient maintenance. The cutting out and replacing of a rivet that has worked loose might also properly be included under maintenance; but the replacing of many such, or the adding of new stiffeners or cover plates to floor-beams or stringers, would come under the head of repairs. This could logically be extended to cover the replacing of the entire floor system or of a lateral system, while the taking

down of the trusses and remodeling them should come under the head of reconstruction.

To give the reader some idea of the various practical difficulties met with in maintaining and repairing bridges, the author offers the following information, which was furnished him through the courtesy of James MacMartin, Esq., C.E., Chief Engineer of the Delaware & Hudson Railway Company:

"Some of the Principal Troubles Met with in the Maintenance of Bridges.

"Bridge Bearings

"In a number of cases of bridges constructed before the general use of a pedestal and pin for the end bearing (other than for pin-connected spans) the masonry under the bearings has become loosened; and in some instances portions thereof have been broken off, due to the deflection of the trusses bringing a bearing upon the front edge of the supporting casting.

"In cases where track stringers rest directly upon the masonry, especially when the bridge is on a skew, the tendency is for the stringer bearing to work itself into the stonework, requiring the resurfacing of the stone and the use of additional plates to bring the track to grade.

"Where the fixed ends of some spans are on the abutment at the high end, when the structure is on a grade, cases have been found in which the bridge has pulled the abutment forward, owing to the rollers being small and not working as they should. A number of the older spans show signs of the bearing plates sliding on the rollers rather than the rollers turning. The use of pedestals with pins for bearings, adopting end floor-beams, increasing the size of rollers, and placing the latter on the abutment at the high end of the span have reduced the above defects to a minimum.

"Track Stringers

"In earlier designs, where I-beam stringers were used and the lower lateral bracing was connected to the bottom flanges of these beams, the holes through the stringers have been found cracked through to the outside of the metal; and, in some cases of end track stringers, the whole bottom flange has parted at this point. Where these I-beam stringers rest on the masonry the webs have been found cracked to a distance of three (3′) feet from the ends, and the said beams have been discovered to be so badly crystallized as to make it necessary to renew all the stringers in the bridge. We have eliminated the use of I-beam stringers from all but a very few of our bridges, and are doing away with them as rapidly as possible. We do not approve of the use of I-beams for floor-beams, stringers, or members subjected to tension; using them only for short spans over cattle passes and culverts. We have experienced none of the above mentioned troubles from the use of built sections.

"In some of our single-web, deck bridges some trouble has been experienced with the lower chord webs at the ends just in front of the bearings. Where there are no angles on top, the webs have cracked from the upper edge down to the bottom flange angles. This has been noticed also on some viaduct spans that were riveted to towers. Where angles are used on the top edge of the webs this defect has not been noticed.

"Rivets

"In cases where floor-beams rest directly on top of the lower chords in through bridges, and on top of the upper chords of deck bridges, a small percentage of the rivets connecting the floor-beams to the chords have been found loose; and we are constantly replacing such rivets. A few loose rivets are occasionally discovered in the connections of the web members to the chords. In cases of single-web bridges of

the earlier design, rivets connecting members to chords have been found sheared, but none in the later design. We find that floor-beams riveted to posts or directly to the sides of the chords give good results, and that the rivets remain tight.

"On bridges where it is necessary to keep barrels of water, we find some trouble with the paint in the vicinity of these barrels. Also we experience more or less trouble from the dripping of refrigerator cars, especially on our half-through bridges, which are only nine feet from centre to centre of girders, and, on that account, expose their top flange plates almost directly to the drip.

"Where abutments for deck bridges are built with a recess, the dirt and refuse have a tendency to collect around the bearings and gather moisture; and in many cases we have found the chords and the bottoms of end posts badly rusted. This condition occurs especially in deep trusses where it is difficult to get down to the bridge seats. Extending the bridge seat for the full width of the parapet wall, and thus avoiding the recess entirely, removes this trouble to a great extent.

"In girders where a cover plate the full width of the bottom chords was used, trouble was encountered due to dirt and cinders collecting in the chords and requiring a great deal of attention from the track men to keep them clean. Using inside angles and two narrow cover plates, where they are necessary, prevents the collection of water and dirt in the chords. It is only in bridges of early design that closed trough bottom chords are in use."

H. Ibsen, Esq., C. E., Bridge Engineer of the Michigan Central Railroad Company, sent the following:

"The principal trouble with the old bridges which we still have in service is, of course, that they have to carry a good deal heavier load than they were designed for. In the old deck, plate-girder bridges, the principal trouble is with the rivets in the flange angles wearing loose at the ends of the girder. This we have remedied by putting in additional rivets where the old spacing is such that this can be done. Where it cannot, we have helped the matter somewhat by reaming out the holes and putting in larger rivets. The best remedy in cases of this kind is, of course, putting in new bridges; and we generally do this as soon as we can after they have shown the effect of overload in the manner described.

"In the old through-girder bridges with floor-beams and stringers the rivets work loose in the floor connections, and the connection angles crack in the fillet. To remedy this, we put in heavier connection angles and larger rivets.

"In the old pin-connected trusses some of the bars in the diagonal members are often loose and wear badly on the pins. This is helped somewhat by clamping all the bars of one member together. Bars also wear at the intersections of counters and main diagonals. This is helped by clamping the two together. Nuts on the floor-beam hangers have a tendency to work loose; this we generally remedy by putting on check nuts where the thread is long enough to permit; if not, we burr the thread after adjusting.

"We have had trouble with the floor-beam webs showing a tendency to buckle at the ends when they are supported by hangers. We remedy this by putting on additional stiffening angles. We have had the same trouble with stringer connections as mentioned in the through girders, and have remedied this in the same manner.

"On our old drawbridges, we have had the same trouble with the bars and floor connections as in the pin-connected trusses; and we have used the same means for remedying it. These old drawbridges had no end lifts, hence there was always considerable hammering at the ends. This caused the rollers at the end to crack and also caused trouble with the track rails at the ends of the bridge. This difficulty we have remedied by putting wedges at the end and sleeve locks on the rails to carry the wheels over the joint in the rails at the ends of the bridge.

"With our new bridges, we have had no trouble except where there are open floors.

On all open-floor bridges, both old and new, the drippings from refrigerator cars cause more trouble than anything else I know of. It is impossible to get any kind of paint that will protect them properly. Usually in bad places the paint will last less than a year on these bridges. In general, the damage is worst at the ends of the old bridges where they rest on masonry, as these bridges have no pedestals under the ends, so that the dirt easily collects around them, and the brine, together with the dirt, very rapidly corrodes the metal. The best remedy I have found with this class of bridges is putting a wooden board about 1″ thick in between the ties, so as to act as a trough to carry off the brine. There is, however, one trouble with this method, and that is that the dirt and cinders collect in these troughs, and it is expensive to keep them clean.

"The larger part of our new bridges are ballast-floor structures, consisting of I-beams with $\frac{3}{8}''$ plate on top of same. With these bridges we have no trouble whatever, except that in some of the older ones the rivets in splices in the floor-plate work loose and cause the floor to leak at these places. This we have remedied by putting in additional rivets in the splices.

"We have had considerable trouble with our old stone masonry, such as abutments, piers, and arches, that are made of Joliet stone. This stone has cracked and spawled quite badly; but we have generally found that taking off the old copings and putting in new concrete ones will bind the abutments and piers well together, thus helping matters considerably."

Modern scientific designing has eliminated many of the defects so apparent in old structures; but familiarity with them will benefit the rising generation of engineers, as there are many old bridges still extant. Moreover, a perusal of the above statements will give them a better appreciation of the *raison d'être* of many of the clauses in the present-day specifications.

The engineer will at times be confronted with the question of the advisability of making extensive repairs, reconstructing the old bridge, or building anew. In deciding such a question, the guiding principle should be that of securing a minimum annual cost. In this the cost of repairs, or of the reconstruction, is to be considered in connection with the length of time that the same will be effective; and it must be remembered that such period of effectiveness is likely to be dependent upon the probable remaining life of the bridge itself rather than that of the repaired details *per se*. The annual cost is found by adding to the interest on the first cost any annual charges for maintenance, etc., and the annuity required to redeem the principal or a portion thereof in the allotted number of years.

Let S = first cost of new structure.

R = first cost of proposed repairs or reconstruction, plus the present salvage value of old structure.

n = the number of years that the repaired structure will be effective.

b_s and b_r = value of old materials in the new and the old structures, respectively, at the end of n years.

C_s and C_r = cost per annum, respectively, of maintaining the new structure and the repaired structure.

M = annual installment to provide a sinking fund to redeem one dollar at the end of n years at compound interest, as given

in Table 65a, which has been taken from Merriman's "American Civil Engineers' Pocket Book."

r = rate of compound interest.

Then
$$M \qquad (1 + r)^n - 1$$

Let A_s = "annual cost" of new structure.

A_r = "annual cost" of old structure repaired.

Then $A_s = Sr + C_s + M\ (S - b_s)$,

and $A_r = Rr + C_r + M\ (R - b_r)$.

TABLE 65a

ANNUAL INSTALLMENT REQUIRED TO ACCUMULATE ONE DOLLAR

(Installments Plus Interest Earnings)

Number of Years	Rates of Compound Interest						
	2%	2½%	3%	3½%	4%	4½%	5%
1	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
2	0.49505	0.49382	0.49261	0.49140	0.49020	0.48900	0.48780
3	0.32675	0.32514	0.32353	0.32193	0.32035	0.31877	0.31721
4	0.24262	0.24082	0.23902	0.23725	0.23550	0.23374	0.23201
5	0.19218	0.19025	0.18835	0.18648	0.18463	0.18279	0.18098
10	0.09133	0.08926	0.08723	0.08524	0.08329	0.08138	0.07950
15	0.05782	0.05577	0.05380	0.05183	0.04994	0.04811	0.04634
20	0.04116	0.03915	0.03722	0.03536	0.03356	0.03187	0.03024
25	0.03122	0.02928	0.02743	0.02567	0.02401	0.02244	0.02095
30	0.02465	0.02278	0.02102	0.01937	0.01783	0.01639	0.01505
35	0.02000	0.01821	0.01654	0.01499	0.01358	0.01227	0.01107
40	0.01655	0.01484	0.01326	0.01183	0.01052	0.00934	0.00828
45	0.01391	0.01226	0.01080	0.00945	0.00826	0.00720	0.00626
50	0.01182	0.01026	0.00886	0.00763	0.00655	0.00560	0.00478

A little reflection will show that it is necessary to take, for purposes of comparison, the life of the repaired structure as a basis for determining the annuities; for after the life of the repaired structure has elapsed it will have to be removed and a new structure built. Whereas, if the new structure had been built instead of repairing the old one, it would still have at the end of n years considerable remaining life and residual value. Hence it is sufficient to figure the "annual cost" of the amount of depreciation of the new structure for "n" years.

For the purpose of making the principle clearer, let us assume that an old structure having a salvage value of $500 can be made serviceable for ten more years (when its salvage will be $100) by expending $1,000 on it for repairs, and that a new structure replacing the old one would cost $2,000 and that it would last thirty years, but that it would gradually depreciate according to some law so that at the end of ten years it would be worth $1,700. Then the annuity must be such that the $300

of depreciation would be replaced at the end of the ten-year period. Rate of interest 5 per cent. Cost of maintenance of old structure 1.5 per cent per annum and of new structure 1 per cent per annum. The annual cost of new structure, for purposes of comparison, becomes

$$A_s = (.05 \times 2{,}000) + 20 + (.0795 \times 300) = \$143.85,$$

while the annual cost of the old structure becomes

$$A_r = (.05 \times 1{,}500) + 22.5 + (.0795 \times 1{,}400) = \$208.80.$$

In this case it would be better to sell the old structure for the $500 and apply it on the cost of the new one.

If the original salvage value of the old structure be neglected, the annual cost would then become

$$A_r = (.05 \times 1{,}000) + 22.5 + (.07950 \times 1{,}000) = \$152.00,$$

which still leaves the new structure the more economical of the two. Generally speaking, if the use of a Hibernianism be permissible, the easiest, most economical, and satisfactory way to repair an old bridge is to tear it down and build a new one.

Observation shows that depreciation proceeds slowly at first and becomes more rapid as time advances and as the loading increases. It is not practicable to state the law that governs the physical processes of deterioration, if, perchance, such a law exists. The eminent bridge specialist, J. C. Bland, Esq., C.E., Bridge Engineer of the Pennsylvania Railroad System, has studied deeply into this question; and in his tentative investigation, which he had to make with most insufficient data, he suggested three methods, two of which he declared to be faulty, and the third only approximately satisfactory. His method, reduced to mathematical form, may be given by the equation,

$$D = \frac{(1+i)^x - 1}{(1+i)^n - 1},$$

where D = the proportional depreciation at the end of x years,
i = rate of interest expressed in hundredths,
n = total number of years of useful life of the structure,
and x = number of years at which the depreciation is figured.

This formula was established by analogy, and no claim is made for its correctness.

The author is of the opinion, however, that the depreciation will vary more nearly according to the ordinates of a parabolic curve, which is expressed by the formula.

$$D = ax^2.$$

If $x = n$, D will equal unity, and

$$1 = an^2 \therefore a = \frac{1}{n^2}$$

and

$$D = \frac{x^2}{n^2}.$$

This is more simple than the preceding formula and is just as likely to be correct; for the more deteriorated a bridge becomes, the more rapid is its rate of deterioration, and toward the end of its life the structure certainly depreciates very rapidly. Truth to tell, *there is no law of rate of deterioration;* for the steelwork of a properly designed, properly manufactured, properly constructed, and properly protected bridge *will not deteriorate at all,* unless the live load be increased beyond a very high limit; and for such a structure if the up-keep be only slightly neglected, the deterioration by rusting will be slow; but it is well known that the more rusted the metal is the more rapidly the oxidation takes place; hence it is fair to assume that, as far as deterioration by rust is concerned, the rate will vary as the square of the life.

In case it is decided to repair or reconstruct an old span, the first step to take is to form a plan for so doing. If the floor system is to be strengthened, the stringers may be doubled up, cover plates may be riveted to the flanges of the floor-beams, and additional stiffeners may be inserted at points of concentrated loading. This was recently done on the St. Louis and San Francisco Railway Company's bridge at Memphis. This sort of repairing generally pays, as the trusses seldom get the full load while the floor system does so quite often. Falsework is not required for repairs of this nature; and the placing of the new stringers can usually be arranged for between trains so as not to interrupt traffic.

Where plate girder spans are to be strengthened, the doubling up process is practicable and not expensive; and it interferes but little, if any, with the regular train service. At times old truss spans can be replaced to material advantage by inserting one or two new piers between the old ones and substituting plate girders for the trusses. This is a good scheme, providing the waterway will permit of such additional restriction and that the Government raises no objections. This method was followed to a large extent by the author in reconstructing the old bridges for the International and Great Northern Railway Company in Texas, and in rebuilding the Black Hawk Chute portion of the Iowa Central Railway Company's Mississippi River Bridge at Keithsburg, Ill. In these instances many of the piers had to be remodeled by taking off the coping and the upper courses of masonry and rebuilding with concrete so as to obtain a larger top. The old spans had to be supported by towers built close to the piers while the tops of the latter were being reconstructed.

When old truss spans are to be replaced, the different members should

be matched-marked in a manner similar to that used by bridge companies on their new spans. Then the metal should be taken down and piled in a convenient place for subsequent shipment.

In the case of renewing a chord section or web member, it will be necessary to build falsework under the span in order to support it and the live load during the period of repairs. Lateral systems can be strengthened or renewed without special difficulty. The replacement of adjustable members in the lateral system with rigid sections is desirable and neither difficult nor expensive; and this change should be made in most cases of repairing railway structures. As shown in Chapter LXIII, it is sometimes desirable to keep an old bridge open for traffic while building the new spans on the old piers. In such a case the new spans must be large enough to enclose the old. Falsework is constructed under the old superstructure, but of sufficient extra width to accommodate the new. This falsework will have to carry the live load in addition to the weight of the new trusses. The trusses and the upper laterals are erected, then the old trusses are dismantled, one piece at a time, the old floor-beams are removed, and the new ones are set in and connected to the new trusses. Then the old stringers are replaced, one at a time, by the new ones; and, finally, new lower laterals are set in and riveted up, after which the falsework is demolished. The carrying of the new metal by the old span without falsework during replacement is sometimes done. See the account of the Kenova Bridge reconstruction in Chapter LXIII.

The repair or reconstruction of substructure, especially below the water line, is attended with more difficulty than is that of the superstructure. It is frequently necessary to enlarge the tops of old piers in order to carry the new spans. It is then essential to support the adjacent spans on temporary towers constructed close to and on each side of the pier. Then as much as is necessary of the top of the old pier is taken off, and a new portion having vertical faces is built on, thus providing a larger area under coping. A further increase can be had by constructing a belting course just under the coping. If additional strength is required, I-beams or girders should be buried in the new top in order to distribute more nearly uniformly the loads over the mass of the pier. Before placing the new top, all holes and crevices in the old masonry should be filled with Portland cement grout. The joints and beds of the masonry courses should have the old loose mortar dug out and new mortar rammed into the spaces and pointed. If the old masonry show signs of disintegration, it can readily be protected by removing all the loose material and thoroughly cleaning the stonework and saturating it with a stream of water. Then any large cavities should be filled with either Portland cement mortar or a fine concrete, after which a wire netting is to be stretched around the entire pier and fastened thereto with spikes. A final coating of mortar is then placed by a cement gun. This method was successfully employed on the masonry abutments of the Chicago & Western Indiana

Railroad Company's bridge over the Chicago Drainage Canal, as related in the *Engineering Record*, Vol. 71, page 337.

Cylindrical piers can be strengthened and enlarged by putting a cofferdam around them, pumping out the water, removing the surrounding material to the foundation, and building a thick concrete casing enclosing the cylinders. In the case that it is not practicable to reach good foundation with the new excavation, piles may be driven in the open space between the old pier and the cofferdam and concrete placed thereon so as to surround the old construction.

In the case of weak foundations, or an unequal settlement, or a crushing of timbers in grillage or in cribs, when it becomes necessary to underpin the base of a pier in order to effect the repairs, an annular pneumatic caisson can be sunk around the old pier, leaving any desired clearance between the two for workroom. Of course, the crib on top of the caisson would have to be extended up at least to the river bed, and a cofferdam would have to be built on top of that sufficiently high to prevent any flooding of the inner space. After sealing the pneumatic caisson the soil between it and the old pier is to be excavated to the base of the pier, then the underpinning operations may proceed, or, if deemed advisable, the old base may be left intact and the excavated space filled with concrete, thereby securing an augmented bearing area and a larger pier shaft. This concrete reinforcement can be carried to any desired height; but unless a portion of the load is effectively transferred to it from the old pier, the increased area of base will not relieve the intensity of pressure on the foundation. An excellent example of this method of repairing piers is given in Vol. LXXIX of the *Transactions* of the American Society of Civil Engineers for November, 1914, the case cited being that of the Little Rock Junction Bridge at Little Rock, Arkansas, owned by the St. Louis, Iron Mountain, and Southern Railway Company. In this case the piers were not located accurately, being two or three feet off centre, thus causing eccentric loading, and the timber crib above the caisson was largely filled with sand instead of riprap. As the sand leaked out, more and more load was thrown on the timbers, and a crushing and settlement of the pier occurred shortly after the completion of the bridge, continuing to increase slowly thereafter until repairs were made fifteen years later. Several valuable lessons can be learned by a careful reading of the above mentioned paper. Among them are that timber cribs should invariably be filled with concrete, that caissons should be sunk with greater accuracy, that cribs should be large enough to admit of some shifting of the shaft of the pier in order that it may be built in exact position, that pier shafts should have more than a bare sufficiency of area under coping to accommodate the shoes of the spans, that some logical method and a system of records should be employed on every job that will fix responsibility, and that the protection of the resident engineer and his principal, the designing engineer, lies in going on record in an effective way so as to offset the scamp-

ing tricks of an unscrupulous contractor, especially in case that the owner takes the part of the latter in his controversies with the engineer, as happens occasionally.

In the late eighties the author was retained as consulting engineer to repair the Missouri River Bridge at Ft. Leavenworth, Kansas, which had been partially destroyed by fire. The bonds of the bridge company were owned in Holland; and the Dutch bankers interested decided to have the structure repaired. They sent over a Dutch engineer to take charge of the work; but as he was not a bridge specialist, the author was retained to prepare the plans and specifications for the repairs and to act as his adviser during construction. The structure was a high bridge, consisting of three Post truss spans that rested on high, cast-iron, cylinder piers only eight feet in diameter. The superstructure detailing was so unscientific and the cast-iron top chords were so cracked that many changes and improvements had to be made in order to repair dangerous flaws and to reduce certain extravagantly high intensities of working stresses to comparatively safe limits. The work cost a little over one hundred thousand dollars, which was a large sum for repairs, considering that the amount of the bonds was six hundred thousand dollars, that the income of the bridge was small, and that the probable life of the structure was only ten or twelve years. Had the calculations described earlier in this chapter been made, it is probable that the bankers would have saved their money and abandoned the structure to its fate. After some ten years of use by the Rock Island Railway Company, its employment for railway purposes was permanently discontinued, and as the income from the highway was inconsiderable, it was soon afterward closed to traffic entirely. Today it stands without approaches a mass of rusting iron that some day will fall and obstruct the navigation of the river.

In concluding this chapter the author desires to express his thanks to Messrs. MacMartin, Ibsen, and Bland for their courtesy in furnishing him with the valuable information herein quoted.

CHAPTER LXVI

STATUS OF HIGHWAY BRIDGE BUILDING

For nearly half a century the designing, letting, and construction of highway bridges have been synonymous with ignorance, cupidity, and graft; and it is only lately that there has appeared to be possible of attainment any genuine improvement in the highway bridge business. In the old days of wooden bridges, when little or nothing was known of the theory of stresses or the principles of design, highway bridges were built much more substantially and honestly; for then the principal material used was cheap, and designers made a practice of hiding their ignorance by an extravagant use of it and by employing in trusses several systems of cancellation, having their members connected more or less substantially at every intersection. Again, in those days bridge building was looked upon as an art, and the building of a bridge was considered a great achievement, consequently bridge construction was attempted only by the most skilful carpenters; and those men, having but little competition to dread, took a pride in their work and built their structures to stay, often protecting them at great expense against the destructive effects of rain and snow by housing them in on top and sides. The excessive use of timber made the bridges so heavy that vibration was checked and the injurious results of impact were reduced to a minimum; and the multiple system of intersection employed so divided the stresses as to relieve materially any member or connection that had a tendency to be overstressed. The consequence of these facts was that the bridges thus built, although unscientific and uneconomic in the extreme, lasted a lifetime; and even today some of them still exist and serve as a monument to the honesty and skill of their builders, who have long since passed away.

But with the advent of iron bridges came a knowledge of stress distribution and the custom of proportioning each main member exactly for the computed theoretical static stress upon it, no recognition being given to the effect of impact, and no real attention being paid to the connecting details. The accumulation of book knowledge, which in those times consisted essentially of theory, caused the public to look with less awe and respect upon the art of bridge building; and very soon not only unskilled workmen but also mere bookworms began to believe that they, too, could build bridges. The result was a great increase in the number of bridge builders, keen competition for contracts, reduction of cost of structures with a more than corresponding reduction in their quality, proportioning solely to comply with set requirements (which were gener-

ally fixed by ignorant commissioners or equally ignorant county surveyors), ignoring of all considerations of rigidity, adoption of extremely light live loads, and, in short, skinning the design and cheapening the construction in every possible manner in order to secure contracts. The effect of this condition of affairs was soon evident, for highway bridge disasters quickly became common, and bridges comparatively new had to be replaced because of glaringly evident weaknesses too difficult to correct. The road roller and the traction engine began to get in their deadly work, and metal structures over railways commenced to fail from corrosion, because of the cheap paint used and the thin sections adopted. Such structures have been rightly named "tin bridges," and their builders have appropriately been dubbed "highwaymen." Indeed, in one sense they are worse, for highwaymen usually demand "your money or your life," while these bridge builders do their best to take both! Their object is invariably to obtain the maximum amount of money for the mininum amount of bridge, and to succeed therein they often find it advisable to "stand in" with the county commissioners. That such "standing in" is not unusual is proved by the following amusing anecdote told by the late C. E. H. Campbell, a well known western bridge contractor, in the columns of *Engineering News:*

"A certain bridge company sent its agent to bid on a large highway bridge. The agent found strong odds against him and wrote his superiors for advice. The company wrote back that a proper amount of 'the long green' judiciously placed where the proper officials would find it, would do more toward securing the contract than all the chin music that he could grind out. Unfortunately (?) the agent lost the letter of advice. It was found by the agent of a rival concern, who immediately had several hundred copies printed and distributed all over the country so as to warn the 'unsuspecting agriculturalists' (who filled the county offices) against those bad persons, and thereby run them out of the business; but, strange to relate, an unprecedented wave of prosperity soon overtook the bad company, and for several years afterward they did a thriving business, often obtaining contracts at higher prices for lighter work than their rivals, and they still continue business at the old stand, over-reaching all competitors."

Soon after the advent of iron bridges, pooling of competitors became an established custom, and this so multiplied the number of bidders that their name became legion. All that a bridge agent or scalper needed in order to obtain his "rake-off" was a bundle of old drawings, some printed forms to fill out, and unlimited assurance. Many amusing stories are told of bridge lettings and of the devious ways of the competitors, a number of which have found their way into print. Here is one that has not:

Some years ago half a dozen "highwaymen" met on a railway train, which they had taken to attend a bridge letting, and there formed a pool with a good commission for each. Mr. T., another "highwayman" and a past master in the art of securing contracts, happened to be in the same train on his way to New York. He knew nothing of the letting, but seeing six of his usual competitors in one of the coaches, he went to his berth

in the Pullman car, took some papers out of his gripsack, made them into a formidable looking roll, and sat still awaiting developments. Presently one of his confrères espied him, and reported to the rest that T. was aboard. They concluded that unless something were done quickly, the pool would be broken, consequently one of their number was authorized to approach Mr. T. and offer him five hundred dollars to keep away from the letting. He went to the Pullman car, sat down by T., and asked him where he was going, to which T. replied, "Oh, I'll be with the rest of you fellows," and pointed to his roll. Then the "highwayman" made his offer, to which T. replied "not for a cent less than one thousand dollars, and cash down at that." After vainly trying to lower the price, the delegate returned to the rest, the crowd made up the required sum (for highway bridge agents and scalpers generally find it convenient in their travels to be well provided with cash), and the delegate handed it over to T., who went on his way rejoicing.

Another amusing story that the author heard lately illustrates the ignorance and worse of the professional "highway bridge scalper." One of them who operated in the northwest had some engineer prepare for him a diagram of stresses and sections for a light, ninety-foot-span, highway bridge; and he used it several times to good effect in securing contracts. On one occasion, having to bid on a ninety-five foot span, he submitted the same sheet, secured the contract, turned the diagram over to the little manufacturing company which furnished him the metalwork for his superstructures, and obtained the material without any comment being offered. Having been so successful in this economic move he tried the scheme again with a one-hundred-foot span, and with like result. Thus encouraged, he gradually increased the span length that he made the diagram serve until he reached one hundred and twenty feet, when the manufacturing company wrote him about the matter, protesting thus:

"You have already stretched that old stress sheet far beyond its elastic limit, and we refuse to be a party to any further stretching."

Pooling is illegal, and in some states it is a criminal offence, punishable with both heavy fine and imprisonment; nevertheless it still exists in the highway bridge business; and as long as bridge lettings are conducted in the manner still in vogue, just so long will the pooling evil continue. County commissioners are themselves to blame for this wretched state of affairs; because they make a practice of advertising for tenders upon competitive plans, and thus attract a huge crowd of bidders to each letting, putting each competitor to considerable expense not only for traveling but also occasionally for preparing designs. Experience has taught the competitors that there is seldom any use in sending a mailed bid, and that it is one of the men on the ground who almost invariably secures the contract. All traveling and bidding expenses eventually have to be paid by somebody, because "highwaymen" are not in the bridge

business for their health; and there is no way except pooling that will enable them to secure reimbursement for their unavoidable expenditures. At first it was customary to arrange for each bidder to add to his tender a lump sum, computed specially for each occasion, to cover the legitimate expenses of all, but this proved so easy that soon the amount was increased so as to add a little profit, and ere long it was made as large as the job would stand; and too often it contained money to be used for corrupting officials. It was not long before these conditions rendered the building of good, ordinary, highway bridges almost impracticable; for, no matter how much money the county was willing to spend on a structure, the builders would take it and would build the cheapest bridge they dared, using the surplus money for commissions to unsuccessful (?) bidders, large profits to the builder, and "parliamentary" expenses. Moreover, it is so hard to break through established custom that highway bridge builders became unable to design and construct good bridges, even if they so desired; because, in the first place, they were densely ignorant of the enormity of their chronic transgressions against good engineering practice (what is customary generally being considered right); and, in the second place, the intellectual status and constructive ability of highway bridge builders, as a body, had been so lowered by the influx of scalpers at bridge lettings that the moral sense of the craft was pretty nearly reduced to zero. This sad state of affairs continued to exist for many years, notwithstanding occasional vigorous attacks upon it and urgent pleas for reform by engineering writers, among others the author. These attacks may have done some good in a few cases, but their general effect was small; for usually it is only the strong arm of the law that can put down public abuses and remove menaces to the lives of the people. Highway bridge failures for year after year have been almost of weekly occurrence, and too often they have involved the loss of human life. Some attempts have been made to legislate against the building of unsafe highway structures, but in most cases these have been failures.

The only practicable way to put down the abuse and to stamp out the current evil practices in bridge construction is to have the various states establish laws appointing competent bridge engineers to prepare plans and specifications for all highway bridges and to supervise their manufacture and construction: and to make it a crime punishable with imprisonment to build such structures in any but the manner prescribed by the law. The expense of maintaining a state bridge engineering force would not be excessive, because standard plans for both substructure and superstructure could be prepared; and these would be used in nine cases out of ten. The appointing of the State Bridge Engineer and his assistants ought not to be left in the hands of politicians, but the Governor should be permitted to select only from a list of applicants endorsed by the American Society of Civil Engineers; and that society should give such endorsements only after a thorough examination of each applicant

on both theory and practice by a committee of bridge specialists chosen from its members.

The advent of the reinforced concrete bridge may prove to be the inauguration of a better state of affairs in highway bridge construction and the means of correcting the crying evils which have existed for so long. Counties that are tired of replacing worn-out and rusted-out "tin bridges" are beginning to call for reinforced concrete structures, because these require very little annual expenditure for maintenance and repairs, and, as far as is known at present, when properly designed and built, they will last practically forever. But the same prostitution of design and the same criminality in building that for decades have been the curse of the metal bridge business are becoming the bane of reinforced concrete construction. It requires engineering skill of a higher order and greater practical experience to plan bridges of reinforced concrete than it does to design steel structures, and the former need much more rigid inspection of materials and workmanship than the latter. The reasons therefor are as follows:

First. The building of reinforced concrete bridges is a new art that is only beginning to be systematized.

Second. Concrete bridges are an eminently proper type of structure for some locations, but for others they are absolutely unfit; and when used in the wrong places they are liable to involve trouble and disaster.

Third. It is just as easy to skin the life out of the reinforcing bars of a concrete bridge as it has been in the past to cut down the sections of steel bridges below the danger limit; in fact, it is far easier, for, when the deed is once done, all proof of it is hidden permanently until after disaster has overtaken the structure.

Fourth. The prevention of the use of improper cement for the concrete throughout the entire construction is a very difficult matter, and a barrel or two of inert cement worked into a critical place might result in the destruction of the bridge. When one span of a concrete arch bridge collapses the others are more than likely to follow suit, the whole structure from abutment to abutment falling down like a house of cards, because the piers are generally incapable of resisting the unbalanced thrust from the dead load of a single span. To make them capable of so doing would involve an expenditure of money that is not warranted, for the dead load thrust of any span should be resisted by that from the adjoining spans, except at the ends of the bridge, where it is taken care of by the massive abutments.

Fifth. The safety of a reinforced concrete bridge is primarily dependent upon a proper proportion of ingredients in the concrete and a thorough mixing of them, and therefore it is at the mercy of the workmen and subject to the vigilance and care of the foremen and the inspectors. The practicing of that all too common and most reprehensible trick of saving cement in order to reduce the cost of construction would involve far more

serious consequences in a reinforced concrete arch bridge than in the piers for a steel structure.

If county commissioners will have the good sense to consult competent bridge engineers before deciding to build reinforced concrete bridges, will retain them to make the plans and specifications and to supervise the construction, and will pay them upon a sufficiently liberal basis to permit of their hiring all the good inspectors that the work needs, they will succeed in effecting a great improvement in highway bridge building. But, alas! this is too much to expect from ordinary county commissioners, who are too often chosen from the ignorant classes for political and other improper reasons; hence it is to be feared that the highwaymen, the scalpers, and the unfit designers will continue to get in their nefarious work, and that reinforced concrete structures will prove no more reliable or durable than the notorious "tin bridges."

Since the preceding was written the author has received a letter from his friend, J. C. Ralston, Esq., C. E., formerly City Engineer of Spokane, Wash., from which, with the writer's permission, the following extract is made. It confirms very effectively the preceding anticipation of future disaster to reinforced concrete bridges designed by incompetent or improperly interested parties. Speaking of a certain highway bridge builder, Mr. Ralston says as follows:

"He is the man who designed and once put forward seriously an arch made of an intrados ring of concrete about four (4) inches thick and an extrados ring of the same thickness, the two rings being separated about twelve (12) or sixteen (16) inches, and this interior filled with a well-rammed, nice, juicy clay. This, of course, furnished an ample play-ground for the neutral axis and the lines of pressure to play hide-and-seek, besides offering special plastic inducements for these frisky functions to stay at home. In fact, I surmise that such a design, in the opinion of the designer, circumscribed their sphere of action within the middle third by barriers of actual concrete. Thus we reach the superlative—the very acme of perfect design, when by such simple mechanical means we confine all such ill-bred functions to an argillaceous field of innocuous desuetude. Need we congratulate ourselves on being members of a profession in which its great leaders weave in such epoch making fashion the dulcet lines of theory and practice into an incomparable fabric of royal perfection?"

But, seriously speaking once more, the reinforced concrete bridge, which certainly has come to stay, is eventually going to prove the cure for the ills of highway bridge building, and the medicine that will effect it is the motor truck. That type of traffic-vehicle has proved itself to be economic, and it has rapidly become heavier, until now its loads rival those of the famous road-roller—that bugbear of highway bridge builders. Furthermore, it must be remembered that the road-rollers traverse bridges so slowly that their impact is assumed to be zero, while the motor trucks pass over at speed, necessitating the usual highway impact allowance; hence in designing the floor systems it will nearly always be found that the motor truck is the ruling factor. The ordinary county bridge of steel trusses with wooden floor is so lacking in strength, rigidity, and mass as

to be incapable of carrying heavy motor trucks with perfect safety; and as these vehicles have no restricted area of operation, and as their use in the country districts is rapidly increasing, it appears likely that light wooden trestles and tin bridges will soon throughout North America have to be relegated to oblivion.

CHAPTER LXVII

BRIDGE FAILURES AND THEIR LESSONS

THE scope of this chapter does not permit of an enumeration of all the railway bridge failures that have occurred since structural designing was placed on a rational basis by Squire Whipple; nor has the author available the necessary statistics for making such a compilation. However, it is desirable that the reader should have an appreciation of the influence that past failures have exerted in advancing the standard of bridge designing and construction and in hastening the adoption of the bridge specialist's recommendations. To the newer generation of engineers, it might seem that the present excellence of bridge design and construction has been attained without much effort. Such, however, is not the case; for the present standard has been reached by a costly weeding-out process—the defects being brought to light by failures of structures or of parts thereof. It has cost a great many lives and dollars to attain the present standard of excellence. The mental inertia of those in authority which had to be overcome was enormous. Improvement has been brought about through the persistent efforts of the consulting bridge engineer by raising the requirements in his specifications so as to keep pace with the acquisition of new facts, and through his insistence that the said specifications be adhered to.

There is always something to be learned from a failure; but too often failures are smoothed over and minimized and given insufficient publicity, so that their lessons are not duly observed nor appreciated. That there have been numerous failures in times past one can readily see by glancing through the back numbers of the engineering periodicals. For instance, the *Engineering News*, Vol. 23, page 373, gives the following table of railway bridge failures covering the period of years from 1879 to 1889, inclusive.

TABLE 67*a*

BRIDGE FAILURES FROM 1879 to 1889

	1879	1880	1881	1882	1883	1884
Bridge failures, iron	3	1	4	6	2	
Total	16	10	38	34	27	33
Miles of track, Jan. 1, each year, 1 = 1,000	81.8	86.6	98.3	103.1	114.7	121.5
Miles per bridge failure	5,110	8,660	2,450	3,030	4,250	3,675

TABLE 67a—*Continued*

	1885	1886	1887	1888	1889
Bridge failures, iron	1	8	7	6	5
Totals	25	20	30	31	22
Miles of track, Jan. 1, each year, 1 = 1,000	125.4	128.3	136.4	149.3	156.1
Miles per bridge failure	5,016	6,415	4,547	4,800	7,090

This table shows a total of 286 failures in eleven years, or an average of twenty-six per annum. Forty-three of these failures were of iron bridges, an average of nearly four per annum. The number of lives lost and persons injured in the eleven-year period is not given, but for the year 1889 there were reported nineteen deaths and sixty-four persons injured in twenty-two wrecks of bridges. In 1889, the last year of the period, there were some 24,450 iron spans and 15,250 wooden spans in service; and of these, five iron spans and seventeen wooden ones failed. Four of these iron spans which succumbed were wrecked by derailed cars and one by a defective pier. Of the wooden-span failures, four structures were burned, three were wrecked by freshets, six were knocked down by derailed cars, and three succumbed from inherent weakness.

In many cases impact due to derailment of cars produced the failure. Lack of precaution at the ends of the structures in the way of guard rails, re-railing frogs, and collision posts was a contributing cause to many of these accidents. Hence it is reasonable to conclude that some of them might have been prevented and the effects of others minimized, and this remark applies to the cases of the burned wooden bridges and those washed out by freshets. In 1895 there were thirty-seven failures of railroad bridges, causing a loss of fifty-seven lives, besides injuring eighty-six persons. Fourteen of these structures were knocked down, five were "square falls," six were destroyed by fire, and five were carried out by freshets. Seven of these thirty-seven failures were of iron or steel bridges, six of which were knocked down and one wrecked by a freshet. Six electric line bridges also failed that year, resulting in forty-six persons killed and nine injured. Further details concerning these failures will be found in the *Engineering News*, Vol. 37, page 93. It will be observed that the year of 1896 shows an increase in failures over that of 1889, which, perhaps, is to be expected, as the number of bridges had increased considerably. On the other hand, improvements had been made in design and construction, and safety devices had been developed, so that if the railroad companies had availed themselves of these things to a larger extent, this number of failures would have been reduced. However, as fourteen spans were wrecked by derailment, six were burned, five failed because of inherent weakness in some part, and five were washed out by freshets, it seems that the lessons of the earlier failures had not been heeded. Moreover, very little publicity was given by the technical press to these accidents at the times of their oc-

currence. Not one of the cases given in the list above quoted from the *Engineering News* was then mentioned in the *Engineering News, Engineering Record,* or *Railroad Gazette.* They were probably considered as of minor importance, and hence were ignored; but one hundred and three casualties for one year are certainly of great importance, because that is a big price to pay for the repetition of lessons which should have been learned at the first teaching—a price paid by the public, not for its own blunders, but for the shortsightedness of railroad authorities who were seeking to make an illegitimate profit from that public. Yet such is the inertia of the human mind that innovations are usually spurned by the majority without even a tryout; and it takes a repetition of impulses to produce action.

The author has not at hand the statistics for later years and, therefore, is unable to say whether the number of failures is increasing out of proportion to the number of bridges in service. However, as a newer generation of engineers is coming into responsible charge of work, he feels that a brief digest of some of the more serious failures of past years will be of service to them. Those failures occurring before the establishment of rational bridge design by Squire Whipple will not be considered.

One of the early failures was that of the railroad bridge over the Gasconade River in Missouri. This was of such serious import that the Directors of the Pacific Railroad appointed a committee to investigate the causes of the accident and report thereon. This report, which was written at St. Louis on November 19, 1855, gives as reasons for the failure light construction and too great speed of train. The design was at fault in not providing adequate sections for the stresses to be resisted.

Another early bridge disaster was that at Janesville, Ohio, in 1866. The report covering the accident was dated at Detroit, Mich., December 13, 1866, and gives the cause of the failure as the "weakness of trussing under the floor-beams"—another case of faulty design in detailing. The Ashtabula Bridge failed in December, 1876, causing ninety-two deaths and sixty-four injuries. Failure occurred in the top chord of the bridge truss immediately under the driving wheels of the locomotive when it was two panels, or 22 feet, from the abutment. This structure was a badly designed Howe-truss bridge, with cast-iron top chords, and was only eleven years old at time of the accident. In addition to the fatalities, this wreck cost the railroad company fully $600,000. This failure led to the abandonment of cast iron for principal parts in future bridge designing.

The St. Charles Bridge over the Missouri River at St. Charles, Mo., was wrecked in 1879 by a derailed car or truck, producing through impact violent abnormal stresses in certain members, some of which were of cast iron. Another serious accident occurred in 1887 on the Dedham branch of the Boston and Providence Railroad, five miles from its terminus in Boston. In this case defective hangers supporting a floor-beam next to the abutment broke, letting the floor system settle so that the cars follow-

ing the engine were stripped of their trucks by contact with the masonry. These hangers were loaded eccentrically—an instance of poor detailing—and they had old breaks which had not been discovered by the regular bridge inspector, who, instead of being a bridge engineer, was a machinist. The *Engineering News*, Vol. 17, pages 190, 204, 207, and 223 gives an extended account and discussion of this failure.

The collapsing of the Atchison, Topeka, and Santa Fe Railroad Bridge across the Pecos River in 1892 was due to the undermining of an abutment and not to any defect in the span. A few hours before the failure an unusually heavy rain-storm raised the water eleven feet above its normal height and to within three feet of the floor-beams. At the bridge site the river made a sharp turn, forming an eddy which produced a scour, undermining the abutment and causing it to tilt forward. As soon as this movement became sufficient to allow the end posts to drop behind the masonry, the weight of the bridge was thrown upon the stringers of the first panel. These tore loose and were raised, and the eyebars of the lower chord were badly bent. Soundings made after the failure showed a smooth flat bed-rock eight feet below water, or twenty-six feet below the rail. That this opportunity for securing a safe foundation was overlooked indicates gross carelessness.

Another instance of substructure failure is that of the four pneumatic piers of the Little Rock Junction Bridge of the St. Louis, Iron Mountain Railroad Company at Little Rock, Ark. These piers were constructed about 1884, but so poorly that trouble was experienced with them from the very start; and efforts have been made during the last thirty years to correct the defects resulting from the contractor's filling the cribs largely with sand instead of the stone called for in the plans and specifications. This sand leaked out, and the small quantity of riprap that was used settled through the crib, leaving the timbers thereof to carry the load unaided. These timbers were not sufficiently strong to bear the burden, and hence were crushed. This condition was aggravated by the fact that the location of the piers was badly done, and the caissons were from two to three feet off centres when finally placed. This condition necessitated the building of the shafts of the piers to one side in order to conform with the span-lengths, thereby placing an eccentric load on the cribs and caissons. Unequal settlement and tilting resulted, so that the shoes of some of the spans overhung the edges of the copings. Impending disaster was narrowly averted from time to time by leveling up and placing I-beam grillage under the shoes. In 1898 extensive repairs were undertaken, and annular caissons surrounding two of the old defective piers were sunk to bed-rock. The space intervening between the old and the new caissons was partially cleaned out and filled with concrete. This was an effective expedient for maintaining the pivot pier in position, but the movement of Pier 4 was not arrested. By 1906 that pier had moved so far that one of the spans was in imminent danger of

falling off. As a temporary expedient; an I-beam grillage was placed under the shoes. In 1908 a steel bent was constructed to support the overhanging ends of these I-beams. The bearing for this bent was secured by building a concrete footing on the wide edge of the crib up to low water. A detailed account of this and further repairs is given by C. E. Smith, Esq., C.E., in Vol. LXXIX of the *Transactions* of the American Society of Civil Engineers. The lesson to be learned from this faulty construction work is that it is both safer and less expensive to use an ample factor of safety in preparing substructure plans and to see that the contractor carries out the essentials of the said plans before he gets his compensation.

In August, 1893, a bridge on tne Boston and Albany Railroad at Chester, Mass., gave way while a through vestibuled train was passing over it, precipitating several of the cars into the river. The bridge was undergoing repairs; and the rivets had been cut out of the top chord of one of the spans for a length of about ten feet. The additional plates had been put on but not riveted when twelve o'clock came and the workmen quit for dinner, the foreman having left the work a half hour earlier. As a result of this carelessness seventeen persons were killed and over thirty injured. Another serious accident occurred during the same year to the Louisville and Jeffersonville Bridge across the Ohio River at Louisville, Ky., the structure being then in process of erection. One of the long spans had been completed and its falsework removed, but the lower laterals had not been placed in the two panels at the south end; while the adjacent long span was partially assembled on falsework. On December 15, 1893, a strong wind caught the traveller, while the guy ropes were slackened preparatory to moving it, and tilted it so that its load of about ninety tons was thrown on one corner for support. This was too much for the pile bent of the falsework, which had previously been weakened somewhat by the scouring of the river bed. The failure of this portion of the falsework caused the rest of it and the partially erected metal upon it to go out, so that practically the entire span was lost. Later in the day the adjacent span above mentioned failed and dropped into the river during a severe wind storm. This span was 550 feet long and weighed about 2,000,000 pounds, which precludes the possibility of its having been lifted and blown off the piers, because the surfaces exposed to the wind were only those of the chords, web members, floor system, and lateral bracing. The probable cause of this failure was reported by an expert to be the temporary bolting up of the splices in the inclined end posts and the consequent inability of the latter to resist the bending moment produced by the wind load; but the author is of the opinion that the primary cause was the omission of the lateral diagonals of the two panels at one end of the span. Without these there was no way to carry the wind load of the lower lateral system to the pier, because, the structure being pin-connected and the hip verticals being of eyebars

only, it could not travel to the hips by vertical sway bracing and thence by the portal bracing to the pier. The omission of these diagonals after the span was free from the falsework was criminal carelessness of the worst possible description; for this accident caused the loss of over twenty lives.

An instance of a failure of a bridge due to the undermining of a pier is that of the New York and Ottawa Railroad Company's crossing of the American channel of the St. Lawrence River near Cornwall, Ontario. Fifteen men were killed in the accident, and sixteen were seriously injured. The erection of the two adjacent spans resting on this pier had been completed. The falsework under one had been removed, and the traveler was being dismantled on the other at the time of the failure. The river at the site of the pier is about thirty-five feet deep, and has a swift current estimated to run from five to eight miles per hour. The river bottom is a clay hard-pan in which boulders are imbedded, many of them being of large size. No borings were made beforehand to determine the thickness of the hard-pan and what material underlay it. This pier was founded by sinking a timber crib and filling it with concrete deposited under water by buckets dumping at the bottom. Before the concrete was placed, divers went down inside of the crib and obtained samples of the bottom, which were deemed satisfactory by the engineer. The first concrete laid was put in sacks and deposited around the sides of the crib, after which the remainder was placed by a yard bucket, and carried up to a plane four feet below water level. Then the crib was pumped dry, and two courses of masonry were set. In this condition the pier went through the winter season and successfully resisted the heavy ice pressures; and in the spring it was struck by a large timber raft which was broken by the collision, but the pier showed no sign of weakening. Shortly afterward the remainder of the shaft was completed and the erection of superstructure was begun. The pier was set at a slight angle with the current and had no riprap about it to prevent scour. This obliquity and some restriction of channel by the falsework and the other piers produced an increase in velocity sufficient to scour and undermine the pier on one side, so that it toppled over without warning, letting the two adjacent spans fall into the river. After the failure, borings were made to determine the nature of the foundation. It was then discovered that the hard-pan was only from eighteen inches to two feet thick, and below that, for a depth varying from twelve to eighteen feet was soft mud or clay. This, of course, should have been ascertained before the plans for the substructure were prepared. The fact that borings were not made renders those in responsible charge guilty of criminal carelessness and makes them accessories to the deaths of the drowned men. That these plans were made under the direction of the Chief Engineer of the New York and Ottawa Railway Company, were approved by the Consulting Engineer of that company, and were further approved by the Canadian

Government engineers without the basic information relative to foundation material—passes understanding. The general fact that glacial drift is extant in all that part of the continent should have aroused the suspicions of the designer and led him to insist on borings being made in order to obtain correct data.

The Erie Railroad Bridge at Buchanan Junction, a few miles from Meadville, Pa., was wrecked in October, 1902. The structure consisted of one central truss span and two half-through, plate-girder spans. At the time of the failure a freight train had partly crossed the bridge. The evidence indicated that one of the posts of the north truss had been hit by a plate-girder floor-beam in transit, projecting from a flat car upon which the load had shifted. This floor-beam jammed against the car behind with sufficient force to break the train in two. The shock of the blow and the momentum of the train behind were sufficient to buckle the post, causing that side of the bridge to drop and to pull the other side down with it. This accident was not due to any defect of the structure.

A suspension bridge at Charleston, W. Va., gave way under a load consisting of a layer of snow and ice four inches thick, twelve teams, and about fifty pedestrians. Two of these were killed outright and others were more or less seriously injured. The primary cause of this failure was an impairment due to the fact that a high water previously rose over the floor at one end, which was at a lower elevation than the other. The pressure of the current caused the bridge to tilt at a considerable angle, which condition produced an excessive loading on the up-stream cable, snapping some of its wires and weakening it so that later it failed. After the water receded, the floor returned to its normal position with many of the wires broken, but it was still used by the traveling public until the time of the accident. Above ground the cables were found by subsequent investigation to be in a much better condition, because of painting, than under the stonework where they were subjected to frequent wettings and had become badly rusted. Many of the wires in the interior of the cables were eaten entirely through. Six years before the failure, the bridge was known to be in a dangerous condition; and several times it was closed to traffic, but after temporary repairs was reopened. The cables that failed were enclosed in anchor masonry, and hence could not be inspected. The lesson to be gained from this case is that the important parts of a bridge should be built so that they may readily be inspected at all times, and that a bridge known to be in a dangerous condition should be replaced by a new structure without delay.

The most stupendous failure on record is that of the Quebec Bridge across the St. Lawrence River, the accident occurring during erection on August 29, 1907. The collapse came suddenly and without appreciable warning to the eighty-five men on the structure. Only eleven of these were rescued, and all of them were more or less seriously injured. This bridge was the longest of its kind that had ever been attempted in any

land, and it was supposed to represent the best product of the bridge builder's art at that time. The fall was due to the buckling of the lower chords of one of the anchor arms. The chord sections consisted of four thick compound webs, with comparatively very small flange angles held together by lacing angles. Each web was made up of four plates aggregating a thickness of $3\frac{1}{2}''$ and angles for flanges at the sides for lattice connection. The dimensions of the chord section were $4'\ 6\frac{5}{8}'' \times 5'\ 7\frac{1}{2}''$. The lattice angles were $4'' \times 3'' \times \frac{3}{8}''$ and the cross struts $3\frac{1}{2}'' \times 3'' \times \frac{3}{8}''$ angles. The insufficiency of this lacing and the lack of stiffening in the flanges of the separate ribs, or webs, were the defects that permitted the chord sections to buckle. This, of course, was faulty designing; but later the designers claimed that there were no precedents for proportioning compression members of that magnitude. However, it was even then generally recognized that in designing all struts the principal radii of gyration should be made as great as possible, and that there should be, in general, some equality of division of the metal between webs and flanges. No reliable theory had then established for proportioning lacing, nor were there any recorded results of tests made on such details for large members. Another contributing cause was the existence of a dead load thirty (30) per cent larger than the bridge company's designing engineer had assumed when making the stress calculations.

The Canadian Government appointed a commission of able engineers to investigate and report on the causes of this failure. An abstract of their report will be found in the *Engineering News*, Vol. LIX, pages 307 and 317.

The lessons to be drawn from this awful disaster are as follows:

First. A consulting engineer should never trust the detailing of a bridge to the manufacturing company, but should prepare complete plans therefor in his own office.

Second. It pays to spread the metal in compression members as much as is consistent with other features of good designing.

Third. There is no excuse for the actual dead load in any bridge exceeding that assumed by more than a mere trifle.

Fourth. One should heed warnings even when they come from uneducated workmen.

Fifth. Plenty of time should always be allowed for making the preliminary studies for a design and the working plans.

Sixth. It is exceedingly bad practice to skin the life out of a bridge in order to save metal.

Seventh. In every important bridge project the completed plans should be checked in detail throughout by some capable bridge engineer who is entirely disconnected from either the consulting engineer or the contractor.

This terrible accident to the first Quebec bridge was a most severe blow to the entire bridge engineering profession in America; for it will be many decades before the European engineers cease taunting their

professional brethren in this country about the failure and its dire consequences. Not a single bridge specialist of any prominence is there in the United States who has not felt more than once the evil effects on his practice of the unpardonable lack of skill and attention which was characteristic of the designing and building of that ill-fated structure.

Thus far in this chapter the failures of highway bridges have not been considered, but their name is legion. So many cases have resulted from incompetency and dishonesty on the part of both designers and builders that it seems hardly worth while to pick out a few specific ones. Until the authorities realize the need of engaging the services of an outside, disinterested specialist, such disasters will continue.

The foregoing examples of railway bridge failures are but a few selected almost at random out of the many that are on record. These are not pleasant things to contemplate, but a careful study of them leads to valuable results, increased knowledge, improved methods, and a keener realization of the responsibility resting on the engineer. In general, failures have resulted from faulty design, inferior workmanship, poor material, or unfair treatment. To reduce these factors to a minimum is the desire of the conscientious engineer, but too often the anxiety of the client to get something done in a hurry or too cheaply is the underlying cause of failure.

Better designing will come with fuller knowledge, better workmanship with improved supervision, better materials with more rigid specifications and testing, and better treatment with more thorough co-operation of the parties handling the work and with a more intelligent appreciation of what the designer is trying to accomplish.

CHAPTER LXVIII

SPECIFICATIONS IN GENERAL

THIS chapter will deal with the characteristics of bridge specifications in general and with the theory of specification writing; while in Chapter LXXVIII will be found complete specifications for designing and in Chapter LXXIX complete specifications for manufacture and erection. The author has dealt with this subject previously at length in his book entitled "Engineering Specifications and Contracts"; and the contents of this chapter are mainly taken from that work, to which the reader is referred for a more thorough and elaborate treatment.

Specifications prescribe the limits of the construction they govern and the qualities of materials and workmanship which enter into it, and they define the relations which shall exist between the parties to the contract, of which they form a part, and the degree of responsibility which attaches to each. If complete plans have been prepared and all the conditions which affect the construction are known and fully considered in advance, the specifications should constitute a full and exhaustive description of the construction, the materials and workmanship employed, the relations between the parties, the responsibility for accidents and for the durability of the completed structure, the terms of payment, and all other matters which affect the work.

Specifications are drawn in the interest of the payer, and they should contain ample safeguards to insure the construction of the work in accord with their letter and spirit; but they should be fair, eminently so, or they will fail in their full purpose. Unless a contractor knows the engineer and his principals to be fair beyond dispute in their dealings, he must add materially to what would be a normal tender for the work, in order to insure himself against serious loss whenever unfair specifications govern. Even a close personal acquaintance and previous experience with the payer and his representatives are insufficient guarantees that an unfair specification will not be enforced, because a change of principals or agents may, often does, take place during the execution of the contract; and a wise contractor will not run the risk of rigid enforcement of the specifications without corresponding compensation. Consequently, every unfair advantage is paid for in the price of the construction, though it is of little or no value to the payer. Unfair clauses in specifications almost invariably operate to the detriment of the party in whose interest they were drawn, by producing a hostile and revengeful spirit on the part of the contractor, leading him to avail himself of every

opportunity to demand extra compensation and extra time allowance for small considerations which are ordinarily overlooked where cordial relations exist. The payer may retain full control over the work and safeguard himself against bad materials and workmanship, against unreasonable delays, and against a contractor's dishonesty without the slightest injustice to the honest contractor, and if such action cause dishonest contractors to refrain from bidding, it is all the more advantageous.

The importance of the specifications, especially of their broad general clauses, is too rarely understood. If the engineer who draws them could exchange places for a time with the contractor, he would soon learn that over-stringent clauses operate to his detriment and, what is even more important, how it is possible to take advantage of his failure to specify definitely what he requires. As a rule, it is the broad general clauses that are most important, for they affect the entire work, while the clauses pertaining to details govern a small portion only. Ambiguous clauses are the most detrimental of all. They insure high tenders; for, in justice to himself, the contractor must assume that the interpretation most contrary to his interests will obtain. They provide the foundation for quarrels, law-suits, and vexatious and expensive delays.

Good specifications are the result of long and sound experience in construction and in the preparation of plans and specifications. If a part of the experience is obtained in the employ of contractors, the results are more likely to be satisfactory. The engineer's knowledge of what constitutes good construction and how to obtain it is the accumulation of years. The foundation for his knowledge—and the foundation only—may be laid during his course of study in a technical school. The weaknesses and effectiveness of the various clauses may be learned only by repeated use, and it is work well spent to review the specifications and contract after the completion of the work they governed, and note the desirable improvements and the fitness of individual clauses for future use. Thus the results of the experience on one contract may be made available for the next, but indiscriminate copying from the specifications of others, or even from one's own, is certain to produce bad results. Some years ago one of the engineering journals called attention to an absurd typographical error in a set of specifications which had been in print for several years, and pointed out the same error in the specifications of several prominent engineers, showing conclusively that some careless copying had been done.

It is impossible for our technical schools to teach men to prepare perfect specifications, but they can provide a good foundation by imparting a sound knowledge of the fundamental principles and such a thorough training in the use of the English language that the student will be able to express clearly what is in his own mind. Professional work, a further study of the law of contracts, and careful attention to the specifications prepared by competent engineers must supply the additional necessary training.

Between the individual or corporation desiring the work done and the contractor who performs it stands the engineer who has designed it and who usually superintends its execution. He is in the employ of the persons promoting the enterprise, and it devolves upon him to make sure that those who retain him receive an honest and fair return for their money. While it is true that he is employed by only one of the parties to the contract, he should not be partisan, but should strive to see that fairness to both is secured. The engineer should not be an enemy to the contractor, but should work in harmony with him, and should do all he can to further the rapid and harmonious completion of the work, being careful, of course, to see that nothing is done which will in any way result in an inferior construction. As the engineer's decisions are usually final (unless it can be shown that actual fraud exists), it behooves him to be careful that no injustice is done to anyone.

In order that the contractor may understand the scope of the work to be performed and the details of its construction, a written description and plans, more or less complete, defining the methods of construction, material, etc., to be used, are prepared by the engineer for the approval of the company having the work done and for the guidance of the contractor. These written documents are the specifications; and together with the contract, of which they form a part, they fix definitely the relations that shall subsist between the company or corporation and the contractor.

To build a structure, no matter how simple, there must be a plan, if it is to be constructed intelligently and efficiently. As the size and importance of the structure increase, the plan grows more and more complex, and hence the greater necessity for putting it in some fixed and definite form which shall convey the exact idea existing in the mind of the engineer. To secure the proper execution of a work of any magnitude, specifications are absolutely necessary, and they should be prepared with great care and exactness. For convenience of reference and for clearness, they are usually divided into clauses, which may be classed as general and specific. General clauses refer to the business relations that shall exist between the parties to the contract. In them is found the general description of the work as a whole without any particular reference to details. Times and methods of making payments, adherence to specifications, inspection, and other analogous headings make up their subject matter. They should be comprehensive in their scope, and should not contradict one another. It is well to avoid a double description of any particular thing. Contradictory clauses are sure to be a stumbling block that will create friction and delay. At first glance one would say that such clauses are easily eliminated, but care is necessary to accomplish this. For instance, a certain result may be desired in the substructure of a bridge that will not fit in with the kind of superstructure wanted.

Specific clauses have to do with the details of construction and the

description of particular features of design. They embody the special ideas that the engineer wishes to incorporate in the work, and they should be just as minute in detail as is requisite to set forth the exact plan desired. Detailed drawings may be necessary to indicate clearly what is to be done, and these drawings either should be prepared before the specifications are written, or at least should be sufficiently matured in the mind of the engineer to enable him to write his specifications in accordance with them. It must be remembered that the specifications and plans constitute a guide book for the contractor and the resident engineer. They should tell what must be done, but should not necessarily state just how it should be done. Specifications should look to the accomplishment of an end rather than to the means of its attainment. Of course, there are exceptions to this, as when the engineer believes that for the best results work must be performed in some particular way, in which case it is necessary to incorporate the method in the specifications. It must be remembered that under these circumstances the contractor cannot be held responsible for the mistakes of the engineer. When an engineer specifies that a thing shall be done in a certain way, he must assume the responsibility of the outcome, because the contractor is not free to adopt the method he thinks best suited to the case in hand. For this reason specifications should leave the method, as far as can be done consistently, to the contractor, and instead should dwell upon the end to be attained. A good contractor who is active and progressive may frequently wish to introduce methods of construction better than those conceived by the engineer, and it were a poor set of specifications which would prevent his doing so. A specification can readily be very strict concerning the finished work and at the same time very liberal as to the methods to be employed in its accomplishment.

It frequently happens that the specifications are written without any accompanying plans at all. In such cases it is usual to require bidders to submit with their tenders plans more or less detailed of what they propose to do. In this way the engineer may make a choice from various plans presented and thus obtain what he considers the best of a number of ideas. Specifications of this kind will have, of course, very little or nothing at all to do with the details involved, but will be concerned almost entirely with the final desired outcome. In other words, such a specification will consist very largely of general clauses, those of a specific nature being either entirely eliminated or reduced to a minimum. This method of letting contracts without any accompanying plans is by no means to be commended. A good engineer does not want other people to tell him what to use or what to do. If he is thorough and well posted in his profession, he is not going to let his own ideas be superseded by those of a contractor who furnishes plans with his bid. In such a case the engineer becomes only an inspector, who simply passes upon the work and determines whether or not it fulfils requirements, when

perhaps much of the work is entirely at variance with his own ideas. It is reasonable to suppose that an engineer who devotes his entire time to designing structures of a particular kind (and no one man will attempt to cover the entire field) is more capable of arriving at the best design for a given case than a contractor who is engaged in work of a varied nature, and who, perhaps, has given little or no thought to the designing of the particular kind of structure upon which he desires to tender. It is undoubtedly a fact that the best results are accomplished when the plans and specifications are prepared by a competent engineer, and when the bidder is governed by their requirements.

Let us consider some of the salient features of good specifications. Primarily, they should give a clear and concise description of the work: first, when considered as a whole, and then in detail, no part being slighted in this description. It will not answer for the engineer to suppose that the contractor will do things as a matter of course, but he must produce a specification that will *insure* their being done. A contractor, if he be thoughtful and careful, will pay close attention to every detail set forth in the specifications, and he should make his bid expecting to fulfil just the requirements enumerated in them, no more and no less. If he be wise, he will not bid with the expectation of having them changed to conform to his convenience or his notions of what is best. The engineer is supposed to have stated in his specifications just what he wants, and no prudent contractor will tender with the expectation that his own ideas will prevail. If, then, upon the engineer devolves the responsibility of determining the work to be done, it will readily be seen that it behooves him to cover the entire ground in his specifications. He should give special attention to the points he intends to require absolutely without alteration and should leave no possibility for doubt in the mind of the contractor as to what will be expected concerning them. He should be careful to set forth clearly the units of measure to be employed and what is to be considered a part of the finished work, as distinguished from what is merely accessory. If extra work is to be performed, the amount of which it is impossible to determine in advance, the greatest care should be exercised in defining clearly just what shall constitute such extra work and in fixing the compensation for it. Failure to do this is frequently a source of trouble and annoyance that might be avoided by careful wording.

Specifications should be designed to secure the best results consistent with what is considered good practice. It is possible to make requirements of such a nature that to fulfil them would mean an enormous outlay of money not at all proportionate to the result. Such clauses in a specification make a bidder uneasy and cause him to add to his bid a sufficient amount in addition to his profit to insure him against loss. A bidder should make his tender expecting to comply with the conditions of the specifications and that his fellow bidders will do the same; and a clause that involves an unduly strict condition is liable to cause

him either to tender high or to bid hoping that its fulfilment to the letter will not be demanded. In nine cases out of ten such a clause will be dearly paid for. Absolute perfection is not to be expected, but the very best that the most approved practice will afford should govern the requirements. An engineer must lose prestige if he specify things which cannot consistently be done, and by inserting such requirements he works injury to all parties concerned. In the matter of materials to be used, he must be governed by the locality and by what the market has to offer. He may be unable to get just what he would like; therefore, he must use the best that can be obtained. These remarks do not imply that the engineer should be satisfied with any makeshift that is offered. He can rest assured that he will not receive anything *better* than he demands, and he is fortunate if he succeed in getting everything as good as he specifies. As he is a large factor in determining what shall be considered good practice, he should not be content to put up with shoddy stuff when better can be obtained. As in all business relations, moderation with firmness should govern.

Again, specifications should be written in simple, plain language without any attempt at rhetoric. All verbs should be complete, and no words should be omitted on the assumption that they are understood. Of course, the law will interpret a contract or a specification in accordance with what the court decides is its spirit, but an engineer should not rely upon this to guard against omission. If the specifications are properly prepared, there should be no occasion for appealing to the courts to decide what is or is not the spirit intended. While such documents should be comprehensive, they should not be verbose; and above all things they must not be ambiguous. Short sentences and simple words are preferred. Punctuation and grammar, while usually and erroneously considered of minor importance in an engineer's practice, certainly play an important part in this particular kind of literature. The meaning of a sentence can easily be distorted or even entirely changed by the misplacing of a comma. Do not fear to repeat the same words or phrases over and over again in your specifications, if you find they best convey the idea you have in mind. This may involve occasionally some lack of euphony, but that can very readily be dispensed with in writings of such a prosaic nature.

Should more than one contractor be employed upon a piece of work, great care must be exercised to define clearly the duties of each. Just where one is to finish and the other is to begin should be set forth so as to leave no possibility of doubt. When practicable in such cases, separate and distinct specifications for the different parts of the work should be prepared. Care should be taken that the same thing is not required of both contractors, and that one contractor is to leave his part of the work in such shape as to involve no hardship or inconvenience for the one who is to follow. As an illustration of cases of this kind, in bridgework it frequently happens that one contractor will do the substructure

work while another will build the superstructure, in which case it is necessary to specify who is to set the anchor bolts and anchorages.

The engineer must be careful about putting anything into his specifications that has even the appearance of favoritism. He must be constantly on his guard to avoid this, for his position is such that his reputation is liable to suffer if he deviate in the least from strict fairness to all. It is bad policy, generally speaking, to require a particular brand of material or the product of a given firm without stating that other material will be accepted, if, upon testing, it be found of equal quality. When a given brand is well known and has an established reputation, it is sometimes proper to specify that it shall be used to the exclusion of other makes, but usually it is best to set a standard which is commensurate with the best product to be had, and then accept any brand which meets the requirements. An exception to this rule is permissible when specifying paint for metalwork, because, unless the particular brand be stated, the contractor is liable to give endless trouble by offering for test inferior brands, and the result is very likely to be the adoption of a paint that is not really satisfactory. Unscrupulous parties are ever ready to give the engineer a bonus in case he use their product, and that engineer is fortunate who has an extensive practice and is yet entirely free from all charges of peccability. Where one man's product is rejected and another's used, there is a great temptation on the part of the disappointed person to question the fairness of the proceeding. An engineer once guilty of crookedness is badly handicapped, and justly so, for no man wishes to entrust the expenditure of his capital to one who is not absolutely above suspicion.

To insure that all the conditions have been enumerated, it is evident that the engineer must familiarize himself with every detail of the work in hand. If he does not understand it himself, it is certain that he will not succeed in getting a clear idea of what he wants into the mind of another. Even when the scheme is perfected in the engineer's mind, it is difficult sometimes to make it plain to the contractor.

It will not do to jump at hasty conclusions, for very often one finds that an idea, which at first seemed to be just what was wanted, proves utterly untenable when considered in connection with other ideas that must be incorporated in order to produce a finished construction. No idea for a specification has any value until it has been fitted into the proposed structure, and is found to harmonize with all the other requirements.

It is usual and proper in specifications to insert a clause allowing the engineer the privilege of changing them or the plans as the work progresses, but it is desirable for all concerned that the number of these changes be reduced to a minimum. A perfect set of specifications would render such a clause useless; but since we have not yet attained to perfection, we must have some means of recourse, bearing in mind, however,

that the more such a clause as the one referred to is brought into use, the farther we are from the ideal.

The question of precision is one which should never be lost from sight. If the engineer is to maintain his prestige, he must be precise. It will not do for him to say "about this" or "about that," for the "about" is very liable to assume proportions which were never dreamed of when the term was used. Of course, there are times when it is neither necessary nor desirable to be absolutely exact in requirements; but, generally speaking, the word "about" has very little place in a set of specifications. What is put into them is placed there with the idea that it is to be operative and binding in the construction of the work, and it is the duty of the engineer, first of all, to impose no impossible or unwise conditions, and next, to see that what he has required is fulfilled to the letter.

The specifications form a part of the contract, as was previously stated; and when the latter is signed, the contractor agrees to all the conditions they set forth. It is proper to assume that he has read the specifications and is familiar with their requirements, and that he signs the contract and makes his bond with the full knowledge of what is before him. A specification should never hide from the contractor the difficulties that are likely to be encountered. On the contrary, when such difficulties are known to the engineer, they should be specially called to the contractor's notice, so that he may bid more intelligently. His attention, however, should not be drawn to them in such a way as to frighten him and to cause him to make a bid abnormally high, but the facts as they exist and are known to the engineer should be stated. As in all relations in life, straightforward, fair-and-square dealing is by far the best policy. No railroad company or other corporation is benefited by letting a contract for a sum below the actual cost plus a reasonable percentage for profit, since the delays incident to the contractor's failure and the litigation that is likely to arise will more than counter-balance the supposed saving. No contractor who is losing money is going to make the same exertion to accomplish his task properly as one who realizes that he is earning a fair profit.

In spite of every precaution that may be taken, it is almost impossible to avoid mistakes entirely. A given proposition may appear to the engineer in his office before work has commenced very different from what he finds it in the field after the construction has begun. When an engineer discovers that he has made a mistake, he should not hesitate to acknowledge it, and to set about, as best he may, to correct the error. He should lose no opportunity to check against errors, and should be thankful when they are discovered in time to prevent harm. To reduce mistakes to a minimum, the engineer must be thoroughly conversant with all contingencies likely to arise in the execution of the work. He should familiarize himself with the appliances ordinarily employed, and should so design his work that their use is not prohibited. In writing his specifications and in making the plans, he should have a clear and complete

mental picture of just what he is striving to attain. It must be remembered that if the specifications are lived up to, they will entirely determine the result, and that it is the plans and specifications wherein the creative power of the engineer asserts itself.

Finally, when all is said and done, common sense must govern the interpretation and execution of any set of specifications. All should have but one object in view—the production of a structure that will be a credit to everyone concerned.

All the bridge superstructure specifications that one meets with may be divided into two general groups: first, those which cover the designing, manufacture, and erection; and, second, those which treat of manufacture and erection only. Specifications of the first type are issued by railroad companies, bridge manufacturing companies, and a few consulting engineers; and those of the second type only by those consulting engineers who do the entire designing of their structures themselves, leaving nothing in the line of detailing to the contractors, excepting the preparation of the shop drawings by elaborating the detail drawings furnished by the engineer.

Whenever a consulting bridge engineer issues specifications that give instructions as to the designing and proportioning, it is *prima facie* evidence that he intends to make a practice of submitting diagrams of stresses to manufacturers for tenders, and letting the successful bidder make the designs subject to his approval. Designs evolved in this manner are invariably inferior to those developed entirely by the bridge specialist himself, and drafted in his own office directly under his own eyes; provided, of course, that the said specialist is thoroughly experienced and competent.

The reader will notice that in this treatise the specifications for designing are entirely separated from those for manufacture and erection.

CHAPTER LXIX

CONTRACTS

THE subject of Engineering Contracts has been treated very fully by the author in his book entitled "Engineering Specifications and Contracts," and the subject-matter of this chapter has been largely drawn from that work, to which the reader is referred for a more complete discussion of the subject.

The dividing line between specifications and contracts is most difficult to draw, for in any particular case two engineers will rarely agree as to what clauses pertain properly to the specifications and what to the contract, of which the specifications form a part. Some engineers prefer to throw nearly everything into the specifications and thus keep the size of the contract proper as small as possible, while others make the latter very extensive by including in it many clauses that are ordinarily found in the specifications. Again, others make a practice of repeating in the contract certain clauses that have already been covered in the specifications, but this method is objectionable in that it is liable to result in conflicting clauses. The author's preference is to throw as much of the matter as possible into the specifications and reduce the size of the contract proper to a minimum, avoiding repetition of statement in the two parts of the work, but of necessity treating certain subjects in both parts, though from different points of view. There is no doubt about the proper place for most of the topics or headings, but in certain cases there are plausible reasons for locating them in either division. All clauses that relate to methods of construction, qualities of materials, character and excellence of the work, rules limiting the functions and powers of the contractor and defining the authority of the engineer, directions to bidders, and transportation of men and materials unquestionably belong to the specifications; but such clauses as those relative to adherence to specifications, alteration of plans, damages, extras, payment, responsibility for accidents, the spirit of the specifications, strictness of inspection, liquidated damages, scope of the contract, and time of completion might, perhaps, be properly inserted in either division. The author's custom, however, is to include all of these clauses and others of like character and scope in the specifications.

The importance of drafting contracts properly cannot well be overestimated. An incorrectly drawn agreement is almost certain to involve serious trouble and often pecuniary loss to an innocent party; hence it

behooves engineers to study thoroughly and fundamentally the science or art of contract writing.

Before one can draft a contract, he must have clearly in mind a full and well defined idea of all the conditions and *desiderata*, and he should epitomize these systematically before beginning to write. It is advisable to keep constantly in view the possibility that each party to the contract may be unscrupulous and willing to take every possible advantage of every weakness which the said contract may contain and which will tend to his own profit—honor and integrity to the contrary notwithstanding. Failure to bear this in mind will often result in some ambiguity that will cause rank injustice to one of the parties to the agreement. It is difficult for an engineer to recognize this weakness of human nature and to keep it constantly before him when writing contracts; because the training and the work of engineers tend to develop in them to an eminent degree the principles of absolute honesty; consequently, it comes hard for them to be forced to make a practice of doubting the integrity of their business associates. To mistrust the motives of one's fellowmen is disagreeable but essential, if the writer of specifications and contracts is to protect himself or his clients from loss and fraud.

The essential elements of any contract, according to Mr. John Cassan Wait, the noted authority on "Engineering and Architectural Jurisprudence" are as follows:

First. Two parties with capacity to contract.

Second. A lawful consideration; a something in excnange for its legal equivalent, a *quid pro quo*.

Third. A lawful subject-matter, whether it be a promise, an act, or a material object.

Fourth. Mutuality: a mutual assent, a mutual understanding, a meeting of the minds of the parties.

Without these four elements no contract is binding in law.

The essentials of a well-drawn contract that comes within the province of the engineer, however, are as follows:

First. A proper and customary form.

Second. A full and correct description of all parties to the agreement.

Third. A thorough and complete preamble.

Fourth. A statement of when and under what conditions the contract is to become operative.

Fifth. The limit, if any, for duration of contract.

Sixth. An exhaustive statement of what each party to the contract binds himself, his executors, administrators, successors, or assigns to do or to refrain from doing.

Seventh. A clearly defined enunciation of the consideration which each party is to receive—this is the essential *raison d'être* of the instrument.

Eighth. The forecasting of all possible eventualities that would materially affect the agreement, and a full statement of everything that is to be done in case of each eventuality.

Ninth. Penalties for failure to comply with the various terms of the agreement.

Tenth. Provision for possible cancellation of contract.

Eleventh. Provision for settlement of all business relations covered by the contract or resulting therefrom in case of cancellation, taking into account all possible important eventualities.

Twelfth. Mention of the place where the agreement is drawn or of the place where it is to be put in force, so as to show the state under the laws of which the validity of the contract is to be determined, should suit be necessary to enforce it.

Thirteenth. Methods of payments, if any are to be made.

Fourteenth. Provision for extra compensation and the limitations connected therewith.

Fifteenth. Provision for possible changes in contract.

Sixteenth. Provision for transfer of the contract or for sub-letting.

Seventeenth. Provision for settlement of disputes.

Eighteenth. Provision for satisfactory and sufficient bond, if any be needed.

Nineteenth. Provision for defense of lawsuits, if such provision be necessary.

Twentieth. Definition of names used in contract, such as "Engineer," "Company," "Contractor," or "Trustee."

Twenty-first. Dating of contract.

Twenty-second. Proper signatures with the necessary seals, if the latter be required.

Twenty-third. Witnesses to the signatures or execution before a notary public.

There will now be taken up and discussed in the order of their enumeration each of these essentials to a properly drawn contract.

First. The styles of opening clause for contracts are both numerous and varied, and it is difficult to say which is the best. Each writer naturally will have one favorite style and will adhere to it whenever possible. The author's for many years has been as follows: (In order to make it more readable the usual blank spaces will be filled out with some assumed names and a date.)

MEMORANDUM OF AGREEMENT, made and signed this eleventh day of February, 1905, by and between the Kansas City Bridge and Terminal Railway Company, a corporation of the State of Missouri, the party of the first part, and sometimes termed in this agreement and in the specifications the "Company," and the Western Contracting Company, a corporation of the State of Kansas, the party of the second part, and sometimes termed in this agreement and in the specifications the "Contractor."

Wait recommends the two following forms of introduction:

This Agreement, made and entered into this eleventh day of February in the year of 1905, by and between, etc., etc.

Articles of Agreement, made and entered into between The Kansas City Bridge and Terminal Railway Company, a corporation, etc., and The Western Contracting Company, a corporation, etc., on this eleventh day of February, 1905.

After the introductory clause comes the preamble, and immediately after it the author inserts in capital letters: "NOW THIS AGREEMENT WITNESSETH," and follows with consecutively numbered clauses that embody all the terms and conditions of the contract, then closes with provision for the signatures and seals of the contracting parties and witnesses to these signatures.

Second. In describing the various parties to an agreement, care should be taken to make the description full and convincing in order that there shall be no possible mistake concerning the identity of each party. This is effected in the case of an individual by stating his occupation and place of residence, in the case of a firm by naming it fully, mentioning its place of business, and describing the kind of partnership, and in case of a company by giving its legal title and the name of the state or country where it was incorporated. In case of a partnership it is sometimes well to specify whether it is general or special in respect to the work covered in the contract.

While most contracts are drawn between but two parties, it sometimes occurs that an agreement will involve three or even more. Such a contract is much more complicated and difficult to draft than one between two parties only.

Each party should be designated in the instrument by his special number, as the party of the first part or the party of the second part; and in addition it is well to give each another designation, such as "Contractor," "Company," "Owner," "Engineer," "Promoter," "Board," "City," "Incorporator," or "Trustee," in order to avoid the use of too many words throughout the document, as would be the case were he always referred to as the party of the first or second part. In order to make assurance doubly sure it is well in some cases to define the terms "Contractor," "Company," "Engineer," "Promoter," etc., at the end as well as at the beginning of the document. In any case these explanatory clauses should be placed at the beginning or the end of the specifications, because the latter are often used without the contract being attached.

There is no strict rule as to the order in which the several parties shall be placed, but it is customary to make the one who pays the money the party of the first part. In case of employer and employee, the employer should come first. In other cases it is a good rule to put the most im-

portant party first and the others as nearly as may be in the order of the importance of their relation to the enterprise or object-matter of the agreement.

There is a consideration of primary importance in contract writing that is sometimes overlooked, viz., whether the parties to the agreement are legally entitled to enter into contract. For instance, in the case of a company, the president or general manager, or perhaps either, can sometimes legally contract in the company's name, but sometimes he cannot, in which case, if haste be essential, it would be proper to have him enter into and sign the contract and afterward have it formally approved at a meeting of the board of directors. A properly certified copy of the board's approval should subsequently be attached to the contract. Access to its charter and by-laws is generally necessary to determine who has authority to enter into and sign contracts for a company.

In contracting no corporation can exceed the limit of its powers as given by its charter. If it attempts to do so, its act will be *ultra vires* and without effect; consequently it behooves one in writing a contract with a corporation first to study well its charter, articles of incorporation, and by-laws.

Contracting with unincorporated organizations as parties, such as associations, clubs, societies, or congregations, is a precarious business; nevertheless it often has to be done. In order to ensure the payment of money obligations by such parties a sufficient sum should be deposited in advance in the hands of a reputable trustee with instructions to pay it to the proper party or parties as soon as the obligations covered in the contract have been met. Otherwise, the other contracting party is liable to lose his entire consideration, because it is very difficult to hold legally an organization that has no legal existence, even if all the members thereof be individually liable.

Again, any person under twenty-one years of age, termed in law an infant, who enters into a contract, has the privilege of repudiating it after arriving at the age of maturity, in case that it does not redound to his advantage; consequently it behooves the writer of a contract to make sure in all doubtful cases that the contracting parties are of age. In engineering contracts, however, this question is seldom likely to arise because very young men are not often concerned in a prominent way with important enterprises.

Similarly, imbeciles, inebriates, and lunatics are incompetent, and contracts made by them are legally voidable at their option. While it is highly improbable that either an imbecile or a lunatic would ever be made a party to an engineering contract, it is not impossible that a man chronically addicted to the over-use of liquor might be so concerned. Such a man might plead that he was under the influence of drink when he signed the document, and thus possibly effect his release from its obligations, consequently the writer of an engineering contract should assure

himself of the temperate character or at least of the sober condition of the parties thereto.

A married woman in some States cannot contract, sue, or be sued in her own name. While it is uncommon for women to be engaged in enterprises involving engineering, it is by no means impossible, as one such case has occurred in the author's practice.

In case of war a contract entered into between parties who are subjects or citizens of the conflicting countries is illegal, and if war be declared subsequent to the signing of the contract, its obligations cannot be enforced by law until after the war has ceased. As engineers are often interested in projects in foreign countries, this is a matter that needs to be borne in mind when preparing the contracts for such enterprises.

When a contract is entered into by an agent, care should be taken to make this relationship both clear and legal in the document by stating the name of the owner or corporation and following it with the words "acting by and through Mr. X., Agent, Attorney, Engineer, President, or Treasurer (as the case may be), by virtue of the authority vested in him through power of attorney of the (here name the individual or company) dated the ——— day of ——— 19—, a copy of which is hereto annexed," or in some similar and equally explicit manner. In this way the name of the real principal is made certain, the authority of the agent is preserved, and the possible liability of the agent as the principal is averted. It must be remembered that no claims or obligations against a principal are created by a contract entered into by an agent who acts without proper authority, unless the contract be afterward confirmed directly or indirectly by the principal.

Much engineering work is being done and is to be done in the future by contract with the United States Government. In making such contracts it is important to note that although the Government may enter suit on its contracts for their enforcement, it cannot, without its own consent, be sued for non-compliance therewith. Instances are not unknown of repudiation of contracts by governments. Furthermore, public officers cannot be held personally liable for contracts signed by them in their official capacity.

The names of the parties in the body of a contract should correspond exactly with the signatures and seals at the end, for a variation might prove fatal to the validity of the document.

Third. The preamble is a most important portion of any contract. It should explain fully all the whys and wherefores of the agreement and its *raison d'être*. A thorough explanation of the agreement there would often render clear the intent of a clause in the body of the instrument that is otherwise ambiguous.

Fourth. Every contract should contain a statement of when or under what conditions it is to become operative. The date may be some particular day of month and year or immediately after, or some definite time

subsequent to, some act or occurrence, such, for instance, as the giving of written notice, or the deposit of a certain amount of money in a certain place, or the completion of a certain piece of work, or the arrival of a railroad at a certain point. Whatever the "condition precedent" may be, it should be made clear in the document beyond the peradventure of a doubt.

Fifth. Too often in contracts nothing is said concerning the duration of the agreement or of how it is to be drawn to a close. In some cases it would be impracticable thus to limit the life of the contract; but in others it is not only practicable but also advisable, and sometimes it is imperative, especially where a bond for proper completion of work is involved.

Sixth. The statement of what each party to the contract binds himself, his executors, administrators, successors, or assigns, as the case may be, to do or to refrain from doing should be thorough and complete in every detail. The importance of this is self-evident, nevertheless it is a point that is not always given proper attention in contract writing.

In all contracts between corporations or between a corporation and an individual, the promises to perform should be made binding upon the successors or assigns of each corporation, although it is probable that the law would enforce this, even if the stipulation be omitted.

In contracts where an individual is a party to the agreement it is best to bind not only himself but also his executors or assigns, unless, perchance, the obligation be of such a nature as to be non-transferable, as for instance, the performance of personal duties or services of an expert nature or involving special skill. Thus an engineer's services are not transferable, unless some special provision be made and agreed to by both parties that, in case of his death or inability for good and sufficient reason to finish his work, his contract is to be assumed by some other engineer either named or to be determined afterward in some specific way. But the death of one member of a firm of engineers will not cancel an agreement; for as long as one of the original members of the firm remains in charge the contract will hold. In other words, it would require the death or incapacity of all the original members of the firm to abrogate the contract, unless special provision to the contrary exist in the written agreement.

Construction contracts are generally assignable, unless they contain provision to the contrary.

Seventh. The consideration which each party to an agreement is to give and is to receive should be clearly and fully stated in the document, otherwise unsealed contracts are liable to be held valueless and void in law. Moreover, the consideration must be real, substantial, and adequate. Some lawyers make a practice in many cases of specifying a consideration of one dollar, and they even try to pass that dollar around among the several parties to the agreement by having each party make

nominally that payment to each of the other parties so as to show that each receives a valuable (?) consideration. In the author's opinion, such a practice is mere humbug and unworthy of adoption by any man pretending to scientific attainments in his profession, no matter whether that profession be law or engineering. Its adoption is *prima facie* evidence of weakness in the document and a confession by its writer that he has failed to make evident the true consideration that each party is to receive and the real reason for each party's entering into the agreement.

There may be some excuse for passing the dollar in case of a parent deeding property to his child, where the true consideration is love and affection; but a dollar does not constitute a real consideration—it would be insufficient usually to pay the cost of typewriting the document, hence its employment is a fiction and a farce.

Eighth. No portion of the work of contract writing requires greater experience and ability than the forecasting of all possible eventualities that would materially affect the agreement and the proper provision for what is to be done in the case of each eventuality. All contracts are more or less faulty in this particular, for it would require omniscience to forecast all future happenings; nevertheless, in preparing an important contract one should endeavor to foresee and provide for all possibilities and probabilities. The lawyer or engineer who makes a practice of giving this important matter full consideration in every contract that he writes will soon find himself in demand by capitalists to aid them in making their investments and in consummating their enterprises.

Ninth. The matter of penalties is one that has to be handled with gloves, for the law is very jealous of its rights and prerogatives, and deems that it alone is authorized to specify and enforce a penalty, which it interprets as a punishment for failure to perform or comply with the terms of an agreement. On this account it is better not to use the term "penalty" in any contract, but to employ instead that of "liquidated damages." The author has a clause in construction specifications that reads as follows:

"For each day of delay beyond the date set in the contract for completing the entire work herein outlined, all in accordance with the plans, specifications, and directions of the Engineer, the Company shall withhold permanently from the Contractor's total compensation the sum of ——— dollars; and the amount thus withheld shall not be considered as a penalty, but as liquidated damages, fixed and agreed to in advance by the contracting parties as a proper compensation to the Company for the loss caused by such delay." Liquidated damages are but seldom enforced, owing mainly to the characteristic good nature of engineers; for they object to taking advantage of a contractor who has worked faithfully but has been unfortunate. Again, the fact that the sympathy of jurors is generally with the working man and against corporations is a

reason why disputes involving the retention of money to compensate for delays are generally settled out of court.

Tenth and Eleventh. In most contracts for construction and in some other types of contract there is no need to provide for a possible abrogation of the agreement, because the completion of the work involved is a natural cancellation; but in some other types, such, for instance, as partnership contracts that continue indefinitely, full detailed provision should be made for annulment at any time. Great care should be exercised to describe fully how all current business matters are to be closed and what compensation is to be paid to the other party or parties by the party who desires the said cancellation. To do this in a satisfactory manner will require business knowledge and ability of the highest order.

Twelfth. It is quite important in many contracts to state where the instrument was executed and where it is to be put in force, notwithstanding the fact that the residence of each party in case of individuals or the state of organization in case of corporations has been described in the introductory clause of tl e document. The laws governing a contract may be determined by the place where the contract was made or by that in which it is performed. Wait treats this question very thoroughly on pages 49 to 51 of his "Engineering and Architectural Jurisprudence."

Thirteenth. Methods of making payments under construction contracts are generally covered in the specifications, where they properly belong. In all other types of contract in which payments of money are involved, full provision should be arranged for the exact manner in which all payments, both partial and final, are to be made. This remark applies with special force to contracts involving engineering fees; for in these, if payments on account are not arranged for, there is a chance that the engineers will receive no compensation at all until after the completion of their work, and this might be delayed for an indefinite period. The author's usual practice is to ask one-half of his fee upon the completion of the plans and specifications and the other half in monthly payments proportionate to the amount of contract work done on the construction, so that when the latter is finished he shall have been paid in full.

Fourteenth. In construction contracts the subject of extra payments also belongs in the specifications, although in many cases it is covered in the contract proper. The author's standard clause for this item reads thus:

"No extras will be allowed, unless they be ordered in writing by the Engineer. For extras so allowed the Contractor will be paid the actual cost to him of materials and applied labor, plus twenty (20) per cent for profit. Satisfactory vouchers will be required from the Contractor for all extra labor and materials. No allowance will be made for superintendence, insurance, or any other indirect expense."

Fifteenth. It is a wise precaution to provide for making changes in

every important contract. The author's standard clause for this item is as follows:

"No change or alteration shall be made in the terms or conditions of this agreement without the consent of both parties hereto in writing; and no claim shall be made or considered for any extra work, unless the same shall be authorized and directed in writing by the Engineer.

Sixteenth. In construction contracts there should always be a clause to govern assigning the contract and sub-letting the work. The author's standard clause for this reads thus: "The party of the second part hereby agrees that it will not assign or sub-let the work covered in this contract or any portion of it, without the written consent of the party of the first part; but will keep the same within its control."

Seventeenth. In respect to provision for settlement of disputes, engineers are somewhat at variance. Some think that the engineer should be the sole arbiter, but such an arrangement is not just, savoring, as it does, altogether too much of autocratic rule. Arbitration is by far the best method of settlement of all disputes on important matters. The author's clause for this item is as follows: "The decision of the Engineer shall control as to the interpretation of drawings and specifications during the execution of the work under them; but if either party shall consider itself aggrieved by any decision it may require the dispute to be finally and conclusively settled by the decision of three arbitrators, the first to be appointed by the party of the first part, the second by the party of the second part, and the third by the two arbitrators thus chosen. In case that the two first chosen fail to agree upon a third, the latter shall be appointed by.....................By the decision of these three arbitrators or that of a majority of them, both parties to this agreement shall be finally bound." The person chosen to appoint the third arbitrator should be some prominent official, such as the judge of a certain court, the mayor of a certain city, or the governor of a certain State. It is seldom that an arbitration clause in a contract is utilized, because engineers as a rule are reasonable.

Notwithstanding the fact that the contract reads that "By the decision of these three arbitrators, or by that of a majority of them, both parties to this agreement shall be finally bound," the law has decided that the losing party has still a right to appeal to the courts; consequently this clause of the contract is not absolutely binding. It would simplify matters if immediately after an arbitration is agreed upon, each party concerned were to give to the other a bond guaranteeing that he will abide by the decision of the arbitrators.

Eighteenth. The bond question is a prominent feature of any construction contract, and occasionally is important in other types of contract. The author has finally come to the conclusion that a good Surety Company bond is the only kind that he shall either ask for or accept in future, for no other kind is so satisfactory to the Company or is obtained

with so little difficulty by the Contractor. All personal bonds are obtained by favor, and they are generally very unsatisfactory; for the solvency of the sureties is difficult to prove, and to enforce payment is still more difficult. There is considerable humbug in connection with sureties to agreements, for a slight change in contract, plans, or specifications is often sufficient to render the bond null and void. If anyone doubt this statement, let him read what Wait says on pages 13 to 17 of his "Engineering and Architectural Jurisprudence." In the author's opinion, the only way to protect the Company is to insist upon having a bond that will permit of all necessary changes in plans and specifications without releasing the surety, and even such a bond might be voided by the law's declaring it illegal because it departs from current practice.

Nineteenth. If, according to a contract, the Contractor is to indemnify the Company against all liability or damages on account of accidents, it is only fair that the former should be given the privilege of assuming the sole defense of all lawsuits arising from such claims.

Twentieth. The manner of defining by special clauses names used in the contract, such as "Engineer," "Company," etc., will be seen in the appended example of a contract.

Twenty-first. A contract can be dated either in the opening or in the final clause, or in both. In the latter case it is better not to repeat the date, but to insert the sentence "Dated the day, month, and year first herein written."

Twenty-second. It is important that the signatures coincide exactly with the names of the parties as given in the opening clause of the agreement, and that proper seals are attached when they are needed. If a party to a contract be a corporation its corporate seal should be used, but in the case of an individual almost any kind of a seal will suffice—either a wafer or the word "seal," with a scroll drawn around it with pen and ink, being commonly used. In the latter case it is better to write in smaller letters the initials of the signer over the word "seal." There is an important and fundamental difference between contracts with and without seals. The former do not need to have a consideration mentioned in them in order to make them valid, while the latter do require such mention. In former times there was far greater difference in the importance of sealed and parole (or unsealed) contracts than there is today; for then a sealed contract could not be modified without taking many formal legal steps, while today it can be changed quite readily by a short supplementary contract, provided there be a proper consideration mentioned therein for the making of the change.

Twenty-third. Where the party to a contract is a corporation, the proper witness to the Company's signature is the Secretary of the Company, who should use its corporate seal for attesting the document; but in case the party is an individual, any witness will suffice. The best possible witness to signatures is a properly authorized notary public; be-

cause if any doubt be expressed concerning the authenticity of the said signatures, all that is necessary is to prove the notary's authority, which is a matter of public record, while for all other witnesses it is obligatory to search for them and either produce them in person or prove that it is impracticable to do so on account of death or departure from the country; and in this case it is generally required that there be brought forward reliable parties who will swear that the witnesses' signatures are authentic.

The following is the form of contract that the author appends to construction specifications:

CONTRACT

MEMORANDUM OF AGREEMENT, Made and signed this......................day of...............19...., at......................., by and between..........

....

the party of the first part, and sometimes termed in this agreement and in the specifications the "Company," and...

....

....the party of the second part, and sometimes termed in this agreement and in the specifications the "Contractor."

WHEREAS,...

....

....

....

....

NOW THIS AGREEMENT WITNESSETH:

FIRST.—The party of the second part, for and in consideration of certain payments to be made to it as hereinafter specified, will................................

....

....

....

....

all in accordance with the plans and specifications hereunto annexed and made a part hereof, and will fully finish and complete the same by...........................

....

....

unless, in the opinion of the Engineer, the party of the second part be delayed or prevented by circumstances that are absolutely beyond its control.

SECOND.—The party of the second part shall start the work of construction as soon after the signing of the contract as it is practicable to begin, and shall push the same to completion as rapidly as possible.

THIRD.—All important dimensions and characteristics of the structure are fully described in the accompanying drawings and specifications, which form a part of this contract.

FOURTH.—In consideration of the performance by the party of the second part of its covenants and agreements, as hereinbefore set forth, the party of the first part hereby covenants and agrees to pay the party of the second part as follows:

....

....

....

....

....

....

In case that there be any other materials furnished by the Contractor that are not included in this list, they shall be paid for on the basis of actual cost to the Contractor plus twenty (20) per cent for his profit, it being understood (as stated in the "Unclassified Work" clause of the specifications) that no indirect expenses of any kind will be allowed in computing the cost of such materials.

It is understood that no payments, either partial or final, are to be made for any material which is to be used for falsework or plant and that payment is to be made only for materials which are left permanently in the finished structure and form a part of it. In order to accommodate the Contractor, however, the Engineer may, at his discretion, allow temporary partial payments in advance of the permanent work as materials for plant and falsework are employed, but the Contractor shall have no right to demand such compensation.

FIFTH.—The schedule prices to be employed in making partial payments for all work as it progresses are to be determined by the Engineer.

SIXTH.—All material paid for by the party of the first part shall be deemed to have been delivered to and to have become the property of the said first party, but the party of the second part hereby agrees to store it and to become responsible therefor during the continuance of this agreement. If any of it be damaged, destroyed, or lost from any cause, including, among others, floods, washouts, and fires, the Contractor shall repair or replace the same at his own expense to the satisfaction of the Engineer.

SEVENTH. -In case the party of the first part, notwithstanding the failure of the party of the second part to complete its work within the time specified, shall permit the said second party to proceed, and continue, and complete the same, as if such time had not lapsed, such permission shall not be deemed a waiver in any respect by the first party, of any forfeiture or liability for damages arising from such non-completion of said work within the time specified, and covered by the "Liquidated Damages" clause of the specifications; but such liability shall continue in full force against the said second party, as if such permission had not been granted.

EIGHTH.—No change or alteration shall be made in the terms or conditions of this agreement without the consent of both parties hereto in writing; and no claim shall be made or considered for any extra work, unless the same shall be authorized and directed in writing by the Engineer.

NINTH.—In the event of any delay in completing the work embraced in this contract, the party of the second part shall be entitled to no extra compensation on account of such delay; as it is hereby assumed that in submitting its tender it took its chances for the occurrence of such delay. If, however, in the opinion of the Engineer, the Contractor be delayed by any act of the Company to such an extent as to cause him serious hardship, such as a temporary cessation of the work, the Company shall allow the Contractor whatever compensation for such delay as may appear to the Engineer to be just and equitable.

TENTH.—The party of the second part hereby agrees that it will not assign or sublet the work covered in this contract, or any portion of it, without the written consent of the party of the first part; but will keep the same within its control.

ELEVENTH.—The decision of the Engineer shall control as to the interpretation of drawings and specifications during the execution of the work thereunder; but if either party shall consider itself aggrieved by any decision, it may require the dispute to be finally and conclusively settled by the decision of three arbitrators, the first to be appointed by the party of the first part, the second by the party of the second part, and the third by the two arbitrators thus chosen. In case that the two first chosen

fail to agree upon a third, the latter shall be appointed by........................

....

By the decision of these three arbitrators, or by that of a majority of them, both parties to this agreement shall be finally bound.

TWELFTH.—As, according to the terms of the accompanying specifications, which form a part of this contract, the party of the second part is to indemnify the party of the first part against all liability or damages on account of accidents occasioned by the omission or negligence of itself, its agents, or its workmen, during the continuance of this agreement, and against all claims for royalties on patents; it is hereby agreed that the party of the second part shall be promptly and duly notified in writing by the party of the first part of the bringing of any suit or suits, and shall be given the option of assuming the sole defense thereof. It is also agreed that the party of the second part is to pay all judgments obtained by reason of accidents or patents in any suit or suits against the party of the first part, including all legal costs, court expenses, and other like expenses.

THIRTEENTH.—The Contractor further agrees to give to the Company a surety-company bond, satisfactory to the party of the first part, in the sum of..............

.................................for the faithful performance of this contract and

the specifications, and of all the terms and conditions therein contained, and for the prompt payment for all materials and labor used in the manufacture and construction of the structures, and to protect and save harmless the Company from claims on patents and from all damages to persons or property caused by the negligence or claim of negligence by the Contractor, his agents, servants, or employees in doing the work, or in connection therewith, and from injury to or loss of materials paid for by the Company either partially or in full before the completion and acceptance of the construction or constructions. In case the contract covers only the manufacture of the superstructure metal, no bond will be required.

FOURTEENTH.—The word "Engineer" as used in this contract refers to the Con-

sulting Engineers of the...

....

....or their duly authorized representative.

IN WITNESS WHEREOF, the parties to this agreement have hereunto set their hands and seals.

Dated the day and year first herein written.

Witnessed by

....	....
....	....

In concluding this chapter there are a few general matters of importance to which the reader's attention is called, especially as they are often ignored in the preparation of contracts.

No erasure with a knife, rubber, or other similar instrument should be made in any legal document, but if a mistake has occurred, it should be lined out in the case of handwriting and crossed out with a close repetition of the letter x in the case of typewriting. Corrections like these

must evidently have been made while the document was being transscribed and before it was signed, while in the case of an erasure no one can say what was originally written, or that the correction was not made after the signing of the document. As a matter of precaution, it is advisable to have each signer of a contract initial on the margin of the page on which it occurs each correction that the document contains. This will show conclusively that all the interested parties concurred in making the changes. However, if a draft of an agreement contain many such corrections, it is better to have it recopied before obtaining the signatures.

Theoretically every contract should be written on a single page, for otherwise what is there to prevent a dishonest person from removing all the pages except the last and replacing them with similar pages containing matter prepared in his own interests? Some people meet this objection by pasting together in one continuous piece all the sheets of the document and marking in red ink on the joined parts a waved line that passes alternately from one sheet to the other. Others take the precaution to have all the parties to the agreement initial each page of the bound sheets. The manifolding of typewritten documents is a fairly good means for preventing the making of fraudulent changes in such papers; but in case that all the copies but one are destroyed, this check would become inoperative.

Contracts executed on Sunday are illegal. They may be agreed upon and drafted on Sunday, but to be valid they must be dated and signed on some other day of the week.

It is always advisable to let a contract "get cold" before signing it, *i.e.*, it should be set aside for at least one night and read over carefully the next day by all the parties in order that each may make sure that the document expresses exactly in every particular what has been agreed upon verbally, and that there is no clause in it prejudicial to his interests. By giving the mind a rest one is often able to comprehend a document more clearly, and thus save himself or his clients future trouble or pecuniary loss.

After an engineer has prepared a contract and has added all the finishing touches to it, he should submit the draft before it is signed to a competent lawyer for his comment. This is better than letting the lawyer draw it in the first place; and although a competent engineer can draft an engineering contract better than any lawyer, nevertheless an independent check is necessary for any important document, and who so competent to check a legal paper as an attorney!

CHAPTER LXX

REPORTS

The preparation of reports, like that of estimates, is one of the most important and responsible classes of work that an engineer is called upon to perform. It involves not only a wide engineering experience but also sound judgment based upon a practical knowledge of business affairs; and no inexperienced engineer need expect to be entrusted with the making of reports of any great consequence.

The reports that bridge engineers are usually called upon to prepare may be included under four heads, viz.,

First. Reports on conditions of old structures.

Second. Reports on values of existing structures and their earning capacity.

Third. Reports on projected structures.

Fourth. Reports upon plans, upon errors and defects in existing structures, and upon methods of construction, either proposed or in progress.

Many such reports have to deal not only with bridges but also with allied constructions; hence the necessity for a bridge engineer to be posted on other lines of engineering than his specialty. For instance, in connection with many bridge projects there are railroad, street railroad, or highway approaches, station-houses, power-houses and plants, terminals, train-sheds, steam or electric machinery, and interlocking plants. These adjuncts complicate greatly the reporting upon bridge projects, and render necessary either a very broad experience on the part of the engineer or the calling in of outside expert assistance. Generally speaking, the more experienced an engineer is in his own specialty, the more likely is he to call upon engineers in other lines to aid him on those portions of his practice in which he does not consider himself an authority; consequently the making of an important engineering report is often the joint effort of two or more engineers who specialize in different lines.

The question of what should and what should not enter into an engineer's report is contingent upon several important considerations. In the first place, it will depend upon who the person is to whom it is addressed. If he be an engineer or a man fairly well posted on the matters treated, the style of the report may be quite technical; but otherwise it should be written specially for the layman; and each reference to engineering matters which it contains should be simple and clear, so that any one of ordinary intelligence may understand it readily. In the sec-

ond place, it will depend upon whether the report is to be published or not. If it is, a formal and strictly correct style, which is not essential in a document of a personal character, will be required. In the third place, it will depend upon who its principal readers are likely to be and how interested they are in the project, for if they are busy men in other lines of work, the report should be as short and concise as practicable; but otherwise it may be made quite full in detail. In any case, though, the text should stick closely to the matter in hand, and should be made no longer than is really necessary to accomplish the desired purpose in the most effective manner possible.

All reports should be written in some logical sequence so as to hold the interest of the reader and prevent its flagging until the last word has been perused. This sequence may be that of time, that of importance, or that of some special consideration peculiar to the subject under discussion.

It almost goes without saying that absolute integrity is a *sine qua non* in the preparation of any report. The writer should take great care to maintain constantly a fair, judicial attitude in order that his advice may not be colored by his desire rather than by his judgment, and to ensure that all favorable and unfavorable considerations may receive their proper weight. A too favorable report may lead clients into an unprofitable investment not only to their ultimate detriment but also to that of the engineer; while, on the other hand, a pessimistic report may prevent the profitable employment of capital.

A masterly style of composition and a fine command of language go far toward making a report successful; but these *desiderata* cannot be attained without a thorough training in the study of one's own tongue. Technical writings, in order to produce the best possible effect, should be characterized by vigor, conciseness, fluency, power, logic, seductiveness, and the capacity to retain interest. Without these attributes engineering reports are liable to fail more or less in their purpose. Concerning the usefulness to an engineer of a command of his own language, the reader is referred to a paper on "The Value of English to the Technical Man," by John Lyle Harrington, Esq., Consulting Engineer, which was delivered as an address to the students of several engineering schools early in 1906, and was published soon after in pamphlet form and copied widely by the technical press. It is to be found also in a book entitled "Addresses to Engineering Students," edited by Waddell and Harrington.

It is by no means easy to outline what reports on bridge matters should contain and how the various questions involved should be treated, because there is no great similarity between the cases which arise in an engineer's practice; but by dealing separately with each of the four previously mentioned types, there may be given a few general ideas that will prove of value.

In reports on the condition of existing structures, one should mention

the location and describe the characteristic features of each bridge examined, should tell what was the live load used in figuring its strength and its ability to carry existing loads, should mention the specifications adopted in determining its actual capacity, should point out all weaknesses discovered and state their gravity, should advise whether the bridge is to be retained (either with or without repairs) or condemned, and should describe fully what must be done to it in order to make it safe as long as it remains in service. A speed limit should be set, if deemed advisable; and an estimate of cost of repairs (if any are to be made) should usually be included in the report.

In reports on the value of existing structures and their earning capacities one should give a full description and a history of the structure under consideration, should state its carrying capacity and its ability or otherwise to transport both the loads to which it is subjected and those which are liable to cross it in the future, should estimate on its probable life and the cost of future repairs, should indicate what an entirely new structure to carry modern live loads would cost, should give a detailed statement of present and probable future annual costs of maintenance and operation, and should show the present earnings and how they are likely to be increased or diminished in the future. If the engineer know the price asked for the structure, he should give his opinion as to its fairness and as to what the bridge is really worth. In short, he should advise his clients fully in every particular about the proposed purchase or sale of the structure, stating clearly and unequivocally all the *pros* and *cons* so that they may be fully informed concerning everything of importance in connection with the pending negotiation.

In reports on projected structures one should describe fully the site, the character of the proposed construction, and all conditions affecting the design, building, and operation of the bridge; should submit detailed estimates of first cost, operation, maintenance, repairs, depreciation, and revenue; should treat of the feasibility of the project from all points of view, and should summarize by making a clear statement of all favorable and unfavorable factors and by giving the resultant conclusion after these have been properly weighed and digested.

In reporting upon designs prepared by other engineers, one is placed in a rather delicate position; because, on the one hand, he must not violate professional ethics by too severe criticism of the work of brother practitioners, and, on the other hand, he must safeguard his clients' interests by pointing out clearly and unmistakably all the defects that he may discover, and he must not hesitate to express a decided opinion concerning the feasibility of the design or the advisability of the project that it illustrates. Each case of this kind as it arises must be settled upon its own merits, for no general procedure can be outlined in advance. The same difficulty exists in reporting upon alleged errors or defects in existing structures and upon methods of construction, either proposed or

in progress; and the preceding remarks concerning the engineer's duty in the case of reporting on designs apply in these cases also.

As examples of the author's methods of preparing reports, the following, which were taken from his practice in 1907, are a good illustration. They are almost verbatim copies, the only changes of importance being the names of persons and places, which good reasons in this particular instance prevent publishing:

Early in October the firm was consulted by Mr. Blank, the general manager of a railroad company, about the replacing of an old and greatly overloaded bridge over the Minnehaha River. The old drawings of the existing structure were submitted by Mr. Blank as the basis of a preliminary estimate of cost for rebuilding or replacing the bridge, it being understood that a more accurate report and estimate would follow later after some borings and other investigations were made. The preliminary report, which was accompanied by a drawing, reads thus:

"In accordance with our promise, we have prepared a layout and estimate of cost of a new bridge and approaches for the crossing of your Minnesota Midland Railway over the Minnehaha River at Carlsbad, and beg to report as follows:

"As you will see by the accompanying blue print, we have made the centre line of the new structure over the main river parallel to that of the old structure, but two hundred feet farther up-stream. Starting from the West side of the main river, the abutment and the first seven piers of the new bridge are located respectively directly above the abutment and the first seven piers of the existing structure, but the eighth, ninth, and tenth of the new piers are about twenty-five (25) feet nearer to the East bank of the river than the corresponding piers of the present bridge. The object of this change of location, as shown quite clearly on the drawings, is to permit the new swing span to be erected on falsework up and down stream without interfering with the operation of the old swing-span or with navigation.

"As we understand that the river is encroaching on the East bank at the bridge site, we have added a one hundred (100) foot plate-girder span at the East end, and have placed it upon a concrete abutment resting on piles driven to bed-rock. The spans of the main river bridge counting from West to East are as follows: Seven, open-webbed, riveted, through, fixed spans of about two hundred and two (202) feet each, one similar span of about two hundred and seventy-six (276) feet, one open-webbed, riveted, through swing span of about three hundred and sixty-two (362) feet, and one half-through, plate-girder span of about one hundred and one (101) feet. All piers and abutments are to be of concrete, the piers resting on pneumatic caissons of timber and concrete sunk to bed-rock, and the abutments being supported on piles driven to same.

"For the bridge over the Red Eagle Chute we have adopted the centre line of the existing structure as the new centre line of bridge, and have counted upon retaining the old piers, if our subsequent examination of them proves that they are either in satisfactory condition or can be put into such, building a new concrete pier on piles midway between each of the old piers, removing the existing spans, and putting in half-through plate-girder spans instead. We have not figured on doing anything to the approaches of the Red Eagle Chute bridge, for the reason that we have not yet examined the old structure. It may be that we shall advise building a short span at each end and resting it on a concrete abutment, but our estimate does not contain an allowance for such extra construction.

"As you will see by the drawing, we have joined the line of the new bridge to the

old line on the Island by a long, easy curve of one degree and forty-six minutes (1° 46′); and at the East end we have adopted a long curve of three degrees (3°) instead of the two curves of the existing line.

"In making the following estimate of cost we have used current prices for materials and labor, but have had to assume from the old blue-print profile that you furnished us an elevation of bed-rock which we think is approximately correct. On account of the uncertainty of the bed-rock data, this estimate must be considered as merely approximate; but as soon as our Mr. Major completes the borings that he expects to start making next week, we shall prepare you a more accurate and a thoroughly reliable estimate of cost. We do not, however, anticipate that it will vary materially from this one.

Superstructure of Main Bridge, including Operating Machinery and House	$335,000.00
Superstructure of Red Eagle Chute Bridge	84,000.00
Substructure of Main Bridge	110,000.00
Substructure of R. E. Chute Bridge	20,000.00
Embankment, 4,000 lin. ft. at $10.00	40,000.00
Small bridge in East Approach	13,000.00
Draw Rest	10,000.00
Removing two old piers	7,000.00
Summation =	$619,000.00
Engineering 5 per cent	31,000.00
Grand total cost of structure =	$650,000.00

"We have assumed that the removal of the old spans will cost you nothing, as the salvage will at least offset the cost. If, though, as we deem probable, the old metal be wrought iron, its value will be greater than the cost of taking it down.

"Trusting that this report will meet with your approval, we remain,

Very respectfully yours,

WADDELL & HARRINGTON."

A month later the second report previously referred to was sent to Mr. Blank. It reads thus:

"On the 18th ult. we sent you a preliminary estimate of cost of your proposed bridge over the Minnehaha River at Carlsbad, based on the old profile furnished by the Central Bridge Company and upon the assumption that the "hard pan" shown thereon was a fit foundation for pneumatic caissons. Again, since we had not then visited the site with the idea in mind of rebuilding the bridge, we had to assume the required lengths of both the main structure and the bridge over the Red Eagle Chute. On these accounts, as stated in our report, the estimates therein contained were subject to revision after borings and other investigations were made.

"As you know, Mr. Major has for some time been making borings; and on the 28th ult. Dr. Waddell visited the site and studied the conditions there. The results of Mr. Major's borings up to date show that near the East shore the so-called "hard pan" consists of a layer of blue clay or gumbo three (3) feet thick, that near mid-stream it is harder and about fourteen (14) feet thick, and that at a point opposite Pier No. 8 there is no clay at all. Below the clay on the East side there is first a stratum of quicksand, then a layer of firm sand, followed by sand and gravel. On this account we have had to abandon the idea of using the pneumatic process, excepting for the pivot pier, and have adopted instead foundations of long piles sunk by water-jets and extending some twelve (12) feet up into timber shells filled with concrete, the top of the shells being placed two (2) feet below low water level. In order to contain the requisite number of piles, these shells or boxes have to be made considerably larger than the pneu-

matic caissons previously figured upon. Thus both the increase of volume and the piles in the foundations augment the cost of the piers.

"Again, we have had to figure on going seventy (70) feet below low water with the caisson of the pivot pier instead of only about twenty (20) feet, as we did in the preliminary estimate.

"The result of Dr. Waddell's visit to the site caused us to lengthen the main bridge about one hundred (100) feet and the Red Eagle Chute structure about four hundred (400) feet, provided that both bridges and the approaches are made permanent in character throughout by replacing all wooden trestle with earth embankment and thus closing all the little openings on the island and on both banks, which openings now permit the passage of water during the flood stages.

"All the preceding modifications have increased the cost over that in our preliminary estimate; but we were fortunately able to make one change that reduced the cost over sixty thousand dollars ($60,000.00), viz., by raising the grade of the Red Eagle Chute Bridge and adopting sixty-six (66) foot deck instead of one hundred and one (101) foot half-through plate-girder spans.

"The following is our revised estimate of cost of a single track bridge, counting from the abutment on the East shore to the abutment on the mainland of the West shore, and including the earth embankment over the island, as well as a small span in the East approach.

Superstructure of Main Bridge, including Operating Machinery and House	$342,000.00
Superstructure of Red Eagle Chute Bridge	58,500.00
Substructure of Main Bridge	171,000.00
Substructure of R. E. Chute Bridge	54,500.00
Embankment	31,000.00
Small bridge in East Approach	13,000.00
Draw Protection	10,000.00
Removing two old piers,	7,000.00
Summation =	$687,000.00
Engineering 5 per cent	35,000.00
Grand total cost of structure =	$722,000.00

"This shows an increase over our preliminary estimate amounting to $72,000.00, which is not excessive, considering the facts that we have had to adopt more expensive foundations and that we have increased the total length of bridge about five hundred (500) feet.

"During your interview with Dr. Waddell on the evening of the 29th ult. you requested us to make for you some estimates of cost of the proposed new bridge on the basis of building the piers for future double-tracking. In compliance with that request, we have made an exhaustive study of all the practicable methods of building at first a single-track superstructure and later substituting for it a double-track superstructure.

"We consider it exceedingly bad practice to load eccentrically any more than can be avoided bridge piers that rest on pile foundations; therefore we have figured on first placing the single-track spans symmetrically on their supports, then moving them laterally when the capacity of the bridge is doubled.

"The following is a list of what we deem to be all the practicable methods of building the structure first for a single line of railway and afterward enlarging it for a double line.

Method No. 1. Build the piers long enough now to carry two single-track superstructures spaced as closely as possible, with a single-track swing-span that has to be

removed entirely in the future and replaced by a double-track swing-span. This method would be necessitated by the inability to stop all river traffic long enough to put longitudinal falsework under the old span, take down the said draw, erect the new swing-span, and remove the falsework. In your case you generally can count upon just sufficient time to do all this, but in certain seasons the ice does not form enough to stop the steamboat traffic.

"*Method No.* 2. Build the piers long enough now to carry two single-track superstructures, with a double-track draw-span of the requisite extra width, but omit temporarily the two outer rows of stringers.

"This method is also suited to the conditions mentioned for the first case.

"*Method No.* 3. Build the piers long enough now to carry two single-track superstructures, and arrange to move the single-track draw-span to one side on the drum and to build a duplicate thereof beside it. This method could not be adopted unless the steamboat traffic were stopped.

"*Method No.* 4. Build the piers long enough now to carry two single-track superstructures, and construct the draw-span according to Waddell's patented method of transforming single-track spans into double-track spans. This method, which will be explained fully later, will not interfere at all with river navigation.

"*Method No.* 5. Build piers nearly but not quite as long as in the preceding cases and the entire superstructure according to Waddell's method just mentioned. The erection of this type of structure would not interfere with navigation.

"Waddell's patented method consists in spacing all the stringers equidistant, leaving out temporarily the two outer lines of stringers and arranging to swing them easily into place afterward, building the floor-beams for the double-track loading, designing the trusses for single-track loading, and arranging to place outside of them in the future duplicate trusses connected to the old ones very rigidly by diaphragms. The new trusses would be erected without falsework by a small overhead traveller and by needle-beams suspended beneath the floor-beams, and they would carry their correct share of the load when properly connected to the old ones.

"The following are our estimates of cost of the structure over the main channel only, exclusive of the engineering, by each of the five suggested methods of construction.

METHOD No. 1

	Original Cost	*Final Cost*
Superstructure.................	$342,000.00	$759,000.00
Substructure..................	322,000.00	322,000.00
Total =.................	$664,000.00	$1,081,000.00

METHOD No. 2

	Original Cost	*Final Cost*
Superstructure.................	$409,000.00	$657,000.00
Substructure..................	322,000.00	322,000.00
Total =...	$731,000.00	$979,000.00

METHOD No. 3

	Original Cost	*Final Cost*
Superstructure.................	$342,000.00	$702,000.00
Substructure..................	322,000.00	322,000.00
Total =.................	$664,000.00	$1,024,000.00

METHOD No. 4

	Original Cost	*Final Cost*
Superstructure................	$361,000.00	$664,000.00
Substructure..................	322,000.00	322,000.00
Total =................	$683,000.00	$986,000.00

METHOD No. 5

	Original Cost	*Final Cost*
Superstructure................	$377,000.00	$605,000.00
Substructure.	308,000.00	308,000.00
Total =................	$685,000.00	$913,000.00

"If the structure be built originally for double track, the cost would be as follows:

METHOD No. 6

Superstructure................................	$566,000.00
Substructure..................................	297,000.00
Total =................................	$863,000.00

"Let us compare these methods so as to determine which is the best.

"If we assume that the rate of interest is five (5) per cent compounded, the following table will give the true total cost of structure after it has been rebuilt for double track at the expiration of certain terms of years.

Method	TOTAL COST IN THOUSANDS OF DOLLARS OF DOUBLE-TRACK STRUCTURE AFTER							
	5 Yrs.	10 Yrs.	15 Yrs.	20 Yrs.	25 Yrs.	30 Yrs.	35 Yrs.	40 Yrs.
No. 1..........	1,264	1,499	1,797	2,178	2,665	3,287	4,080	5,072
No. 2..........	1,181	1,439	1,768	2,187	2,723	3,407	4,281	5,372
No. 3..........	1,207	1,442	1,740	2,122	2,608	3,230	4,023	5,014
No. 4..........	1,174	1,416	1,722	2,125	2,616	3,255	4,071	5,091
No. 5..........	1,102	1,344	1,652	2,045	2,547	3,188	4,007	5,030
No. 6..........	1,101	1,406	1,794	2,290	2,922	3,729	4,761	5,050

"From this table it will be seen that at the end of five years it is a stand-off between Nos. 5 and 6; that for ten, fifteen, twenty, twenty-five, thirty, and thirty-five years No. 5 is the most economical method, and that after about thirty-eight years No. 3 is the most economic. Or, in other words, at the end of five (5) years the cost of the double-track bridge and that of Waddell's special structure are the same, from five (5) to about thirty-eight (38) years the special structure is the most economic of all, and after thirty-eight (38) years the method of duplicating the spans throughout is best. As there is practically no chance of there being any necessity for double-tracking during the first five years, and as the call for greater capacity will in all probability come before thirty-eight years, it is evident that Waddell's special structure is the best one to adopt.

"Assuming this to be the case, the following table gives our estimates of total cost for the various cases that you will probably consider.

"There is another possibility that we have not yet considered, viz., that when greater capacity is required, it might be more economical to build another single-track bridge either above or below the old one and as close to it as the War Department and the existing conditions will permit. The least allowable distance between bridges is, ac-

Items	Single-Track Structure	Double-Track Structure	Waddell's Special Structure, First Cost	Waddell's Special Structure, Final Cost
Main River Bridge	$513,000	$863,000	$685,000	$913,000
Red Eagle Chute Bridge	113,000	202,000	144,000	204,000
Embankment	31,000	40,000	31,000	40,000
Approach Span	13,000	22,000	13,000	22,000
Draw Protection	10,000	17,000	18,000	18,000
Removing old piers	7,000	8,000	9,000	9,000
Summation	687,000	1,153,000	900,000	1,206,000
Engineering	35,000	58,000	52,000	60,000
Grand Total	722,000	1,211,000	952,000	1,266,000

cording to law one-third of a mile. There are two objections to this method: first, the extra cost of the single-track embankment between the junctions of the new and the old lines, which we may assume to be about one hundred thousand ($100,000); and, second, the extra expense of operating two swing-spans, the capitalized cost of which would be about fifty thousand dollars ($50,000).

"Upon these assumptions we have figured the total cost of obtaining the increased capacity for traffic at different periods, and have recorded the results in the following table.

Type of Structure	Total Cost in Thousands of Dollars for Increased Capacity After							
	5 Yrs.	10 Yrs.	15 Yrs.	20 Yrs.	25 Yrs.	30 Yrs.	35 Yrs.	40 Yrs.
Double Track	1,547	1,974	2,520	3,216	4,105	5,329	6,687	8,498
Waddell's Patented Structure	1,529	1,865	2,293	2,841	3,538	4,428	5,566	6,988
Two Structures	1,795	2,048	2,373	2,787	3,317	3,992	4,855	5,933

"From this table it is evident that under no condition whatsoever would it be economical to build a double-track structure at present, unless the traffic for it were plainly in sight; and that for seventeen (17) years the special type of structure would be most economical, after which two separate structures would be better, provided that there be a good and suitable location within a mile of the present one.

"In case that you adopt the special type of construction and we prepare the plans for you, there would be no charge for royalty on account of Dr. Waddell's patent.

"Although our Mr. Major has not yet finished making the borings, the results so far obtained are sufficient to assure us that his complete report will not greatly modify the above estimates of cost of foundations, And though these estimates are not final, they will, we trust, enable you to reach a conclusion at an early date regarding the type of structure to build, an end which the condition of the present structure in our opinion, renders urgently desirable.

"You asked Dr. Waddell what are the probable amounts of money that you would have to spend from month to month on your proposed new bridge, provided that the work of construction be pushed as rapidly as practicable; and we have, therefore, made computations from which we reach the following conclusions:

"Assuming that on January first you give us an order to proceed with the preparation of plans and specifications and to call for bids as soon as possible, the money to pay for a single-track structure would be required in about these amounts and times.

April 15	$30,000	Oct. 15	$170,000
May 15	24,000	Nov. 15	80,000
June 15	24,000	Dec. 15	30,000
July 15	30,000	Jan. 15	62,000
Aug. 15	120,000	Mar. 31	7,000
Sept. 15	145,000		
		Total =	$722,000

Please note that estimates are made on the first of each month and that the corresponding payments become due on the fifteenth of same. The April payment includes one-half of the entire engineering fee, which, according to custom, is due upon the completion of the plans and specifications, the remainder being paid monthly in proportion to the monthly estimates for construction. The May, June, and July payments cover substructure only. Those for August, September, and October include the delivery of all the superstructure metal at site, as well as substructure work and the commencement of erection of the spans. The January figure is high because it includes the reserved ten (10) per cent. The March estimate is for the removal of certain old piers, which work cannot be done until after the new structure is in operation and after the old spans are taken down. We have made no allowance for the cost of removing the old spans, as this would be more than offset by the value of the metal therein.

"The corresponding figures for a single track structure on double track piers, with the swing span built according to the patented method are as follows:

April 15	$44,000	Oct. 15	$204,000
May 15	42,000	Nov. 15	120,000
June 15	42,000	Dec. 15	34,000
July 15	54,000	Jan. 15	66,000
Aug. 15	148,000	Mar. 31	9,000
Sept. 15	180,000		
		Total =	$943,000

"The corresponding figures for a single track bridge on double track piers, with the entire superstructure built according to the patented method are as follows:

April 15	$46,000	Oct. 15	208,000
May 15	41,000	Nov. 15	118,000
June 15	41,000	Dec. 15	35,000
July 15	52,000	Jan. 15	68,000
Aug. 15	150,000	Mar. 31	9,000
Sept. 15	184,000		
		Total =	$952,000

"We have assumed January first as the best time to start your construction, for the reason that by so doing you would be able to complete the new bridge in twelve months. If you were to start at an unfavorable time, it might require a little longer.

"We trust that this report will make clear to you everything in connection with the economics of your crossing; but if you desire any further explanations or investigations, we shall be pleased to furnish them.

"Very respectfully yours,

"Waddell & Harrington."

CHAPTER LXXI

ADMINISTRATION OF CONSTRUCTION

THE method of letting construction contracts at cost plus a percentage or cost plus a lump sum has been gradually coming into vogue in some of the large cities, but it is never likely to replace the old-fashioned method of letting them in competition by contract at schedule rates. There is a good deal to be said on both sides of the question. The side of the advocates of the "Percentage Method of Performing Difficult Work" was so well stated by an anonymous writer in *Engineering News* of October 10, 1891, that the author has decided to copy from the letter referred to the following presentation of their case:

"The owner is assured from the start that the work will be well done, because the chief temptation for slighting it has been removed. He is also assured that labor and material bills will be paid and that there will be no liens against the completed structure. He is at liberty to make various changes in the work while under progress, without first obtaining the consent of the contractor, and he is enabled to put a reliable contractor at work on the job as soon as the principal features are determined on, without waiting for all detail plans to be completed.

"If there is any uncertainty about the nature of the obstacles to be encountered, the extent of possible difficulties and delays, or the details of construction, no contractor of experience will make a bid on the work without allowing for contingencies. In this way the owner has to pay a large sum for the risks assumed by the contractor, and he might as well take some of those risks himself. Again, in a complicated piece of work some bidder may carelessly omit or overlook some expensive items in making up his estimate of cost, and thus get the work awarded to him at less than the actual cost. It is better for the owner to pay what a job is actually worth; for when a contractor is losing money, either from his own mistakes, including omission in making up his bid, or from difficulties that could hardly have been anticipated, it is but human nature for him to endeavor to get even in some way, and the character of the work will suffer in consequence, despite great care and watchfulness on the part of the engineer. And it is difficult for the average engineer, when he sees a contractor bravely struggling with an unprofitable job, to harden his heart to such an extent as to require all the nicety of construction that he would exact if he knew the contractor were making money on the work.

"With the percentage method the owner is at liberty to make the work as costly or as cheap as he pleases. He should have his own trusted employee to supervise the accounts, and he should be careful to select the right contractor. There are plenty of honorable and capable men among contractors who would work faithfully for the interests of their employers, if given a contract on the percentage basis."

The author acknowledges that there are conditions which would make the method of letting work at cost plus a percentage or cost plus a lump sum, or even the method known as "day labor," preferable to the ordi-

nary method of letting by contract at schedule rates; but such conditions are unusual. In his opinion, the adoption of any one of the three first-mentioned methods is a last resort, applicable only when it is impracticable to secure good contractors to undertake the work on the usual basis. No matter how honest or honorable a contractor may be when working on a "percentage" job, there is no ensuring that his employees are equally honest or honorable. In fact, one can count confidently upon their not being so; consequently, when there is no one on the work to drive them to exertion, they will "soldier" to such an extent that the construction will eventually cost from fifty (50) to one hundred (100) per cent more than it ought. Human nature is human nature the world over; and, unfortunately, it is so constituted that, especially in the lower walks of life, man will not labor to advantage without some mental spur or personal incentive. When a workman feels that the more a piece of work costs the greater will be the profit to his employer, he will not dread greatly being discharged on the plea of laziness. The author is speaking advisedly and of what he knows, for he has done some millions of dollars' worth of bridge construction by administration; and, although his contractors were honorable and desirous of doing the work expeditiously and economically, nevertheless it was practically impossible to make the workmen exert themselves as they would have done under the usual conditions of contracting.

As for doing important bridge construction economically by day labor —that is a myth and a dream, as any railroad company which has tried it will testify. It is difficult to make the day-labor method pay even on such small work as ordinary bridge maintenance and repairs, and when such jobs are large railway managers find that it is economical to contract them to bridge builders, even if it should become necessary to do so at cost plus a percentage.

A short time ago the author had occasion to call for bids for the installation of some gasoline machinery to operate one of his old swing bridges which had for many years been turned by man-power. The tenders were all so high that he advised his client to do the work by day-labor, the result being that the actual cost exceeded that of the highest bid. It is true that more work became necessary as the installation proceeded, and this would have occurred under any conditions; nevertheless he became convinced through this experience of the futility of trying to save money by doing repair work to bridges by the day-labor method.

Where bridge construction is done in a foreign country, it may be found necessary to adopt the cost plus a percentage plan, but there should be a limit to the contractor's total profit; and, in fact, it would be better to reduce his profits by degrees after certain previously determined total costs for the various structures have been exceeded, making it disadvantageous for him to let the cost of construction be excessive.

Where foundations for bridges are of an unusually difficult character, it may be advisable to let the work at cost plus a lump sum to a substructure contractor of experience and well-established integrity; because bidders are prone to tender exceedingly high when they have to meet unknown or uncertain conditions. If such work be let at schedule prices in the usual manner, and the contractor's estimate of cost prove to have been too high, the principal will have spent money that otherwise might have been saved; while, on the other hand, if the contractor's estimate of cost prove to have been too low, the worries, troubles, and delays that always ensue under such circumstances will, in one way or another, make the principal wish that the contract had been let on a more liberal basis.

There is a method of letting contracts, evolved and advocated by Mr. C. F. Graff, President of the Graff Construction Company of Seattle, Wash., which is far more satisfactory than that of cost plus a percentage or that of cost plus a lump sum. It consists in guaranteeing a limiting lump-sum expenditure to the client for the work, at which figure the contractor's profit will be either zero or a minus quantity, and naming as possible actual costs a number of other smaller and regularly decreasing sums with a regularly augmenting sliding scale of percentage thereon to be added for contractor's profit, the latter being so arranged that the client and the contractor will share by another sliding scale the difference between the greatest possible price and the actual cost, the larger the saving the larger the percentage thereof to go to the client. Barring the standard methods of lump sum and unit prices, there can be conceived no better, fairer, or more systematically adjusted means of letting contracts than the preceding. The client is protected by bond against excessive expenditure, and the contractor is given the best possible incentive for keeping the cost down to the lowest practicable limit. It goes without saying that the client has the privilege of auditing the contractor's accounts, or even of keeping a combined inspector and auditor on the work from start to finish so as to see that all payments for labor and materials are *bona fide* and that all the construction is done both thoroughly and economically. In view of the importance of this proposed scheme for letting contracts, and because the preceding description of it may not be perfectly clear to every reader, the author has concluded to illustrate it by an actual example taken from Mr. Graff's practice, and to let him explain in his own words the important advantages of his method.

In May, 1912, Mr. Graff made a written proposition to the City Council of Victoria, B. C., for the construction of the Sooke Waterworks, from a published copy of which the cost and profit table has been compiled and the appended extracts have been taken:

"The total expense to the city is thus guaranteed not to exceed $1,450,000, the said guarantee to be covered by a satisfactory surety bond. The company proposes

that the percentage of profit for costs intermediate to those shown shall be computed on the principle of direct proportion. . . .

TABLE 71*a*

CONTRACTOR'S COST AND PROFIT TABLE FOR PERCENTAGE BID ON THE SOOKE WATERWORKS, VICTORIA, B. C.

Actual Cost in Dollars	Profit on Actual Cost		Total Cost to City in Dollars	City's Saving on Guaranteed Maximum	
	Per Cent	Dollars		Dollars	Per Cent
1,450,000	0	0	1,450,000	0	0.0
1,430,000	1	14,300	1,444,300	5,700	0.4
1,410,000	2	28,200	1,438,200	11,800	0.8
1,390,000	3	41,700	1,431,700	18,300	1.3
1,370,000	4	54,800	1,424,800	25,200	1.8
1,350,000	5	67,500	1,417,500	32,500	2.3
1,330,000	6	79,800	1,409,800	40,200	2.8
1,310,000	7	91,700	1,401,700	48,300	3.3
1,290,000	8	103,200	1,393,200	56,800	3.9
1,270,000	9	114,300	1,384,300	65,700	4.5
1,250,000	10	125,000	1,375,000	75,000	5.2
1,230,000	11	135,300	1,365,300	84,700	5.8
1,210,000	12	145,200	1,355,200	94,800	6.5

"We have submitted a proposition to the honorable water commissioner on a sliding-scale cost, plus a percentage basis, which becomes automatically economical from the view-point of the municipality as well as ourselves as managing contractors for the city in this, that as the total cost of the work is reduced the percentage of profit is increased, and as the cost is increased the percentage of profit is reduced until, when the cost reaches a certain fixed maximum, these profits become zero, and we guarantee that the total entire cost to the city, including plant, profits, and all charges of every kind, shall not, in any event, exceed this fixed maximum, and this guarantee is to be covered by a satisfactory surety bond to protect the city. . . .

"We respectfully invite the attention of the council to the fact that unless some such principle as here outlined by us is resorted to, there is no assurance, so far as the city is concerned, as to what the ultimate cost of the work will be, whereas by our proposed method there is every incentive for the managing contractor to keep the cost down. It is, in fact, absolutely essential that he do so, or his efforts will all be exerted for nothing. We consider, and so will every sane business man, that for the city to enter into a cost plus a percentage or fixed sum profit agreement without a guaranteed maximum cost would be ruinous; that even with such a guaranteed maximum cost there is not the incentive to keep down the expense of the work that exists under the arrangement we propose. Our offer is a straight business proposition which puts the whole responsibility of sound, economic, and scientific management directly and solely upon the shoulders of the contracting manager equally as much as though he were handling the work on a straight contract; and at the same time the proposition meets the necessity of completing the work on a cost basis, which is the only legal defensible procedure now open to the city in view of existing conditions. By this method not only is the city absolutely sure of its position as to the worst that may happen financially, but if, as the work progresses, it proves to be a fact that the cost of the project is less than the general judgment now seems to indicate, then the city of Victoria will reap the benefit. Also, although as pointed out above, the principle involved automatically ensures economy, we would suggest that the city adopt some independent method of checking the pay-roll and the expenditure

for materials, but it should be borne in mind that to secure the best and most economic results, and in the best interests of the city generally, the contract manager should be left absolutely untrammelled and allowed to enter the buying market and otherwise to conduct his operations as though he were executing a straight contract. . . ."

Where bridge construction is done by administration, the labor involved for the engineers is far greater than that which they would have to perform under the usual method of letting such work; for, in addition to their customary duties, they must approve the contractor's entire plant and must O. K. in advance the purchase of all the materials used, wages and salaries paid, and every expense of every kind connected with the construction. They must also look to the location and sanitation of all camps for the workmen, arrange for hospital accommodations and medical attendance, see to the insurance of men and materials, inspect the drinking water and make certain that it is boiled or otherwise purified, and have an eye on the commissariat, the stores, the camps, and the boarding of the men, so as to ensure that they are looked after and fed properly and at reasonable rates for the accommodations furnished. Again, the engineers must look carefully after the pay-rolls so as to see that all the money so charged goes to the employees, that the wages are properly adjusted to the different classes of labor, and that the men's time is correctly kept. Besides all these items of extra trouble and expense, the records of work done will be much more complicated and troublesome to keep. In short, the work that the engineers are called upon to do under the method of administration is excessive, and their responsibilities are increased greatly as compared with those involved by the usual method. On this account, as explained further in another chapter, they should receive increased compensation for their services when the construction is done by administration.

CHAPTER LXXII

ARBITRATION

Although many specifications (the author's included) contain a clause concerning arbitration, it is not often that this method of settling disputes is adopted. Were it in more general use, there would be fewer cases in the courts involving controversies between builders and contractors. Arbitration is an easy and inexpensive manner of settling disputes, and it ought to be satisfactory to all who desire to do what is right and who have no wish to take any undue advantage. When a board of arbitration consists of three engineers, one appointed by each of the contestants and the third by the two thus chosen, the decision reached is more likely to be just and equitable than that arrived at by either judge or jury; because the arbitrators are men trained by their life's work to consider just such questions as are raised in a controversy of this kind. Moreover, the average engineer is an eminently fair-minded man; hence there is every chance of the arbitrators' verdict being the best that can be reached. In treating disputed matters engineers almost invariably consider them from the point of view of equity and justice and not from that of the law, and in so doing they are right; for the law is often hide-bound and arbitrary. Lawyers and judges too often cling closely to precedent and to the letter of the law, ignoring individual rights and the calls of justice; hence they are not so well fitted to act as arbitrators on engineering matters as are engineers.

There are two classes of arbitration with which a bridge engineer is called upon to deal. The first and most common is the adjustment of disputed points in the final settlement for a construction contract. The second is the determination of what proportion of the total cost of a structure, either proposed or completed, each of two or more interested parties ought to pay. Ordinarily, the adjustment of a final settlement is no difficult matter after both sides have stated their claims and points of view, for if the sense of equity does not indicate clearly the correct determination, compromise is resorted to, and a decision is soon reached. But the determination of what each one of several joint owners or users of a structure should contribute to its cost is no simple affair. It involves many deep and intricate questions that sometimes appear almost incapable of solution.

One instance in the author's practice will illustrate this complexity. A certain Western city had retained him to design and supervise the

building of a large and expensive bridge to carry wagon, pedestrian, and street railway traffic; and the street railway company was to contribute its proper share of the expense of construction. The city officials thought that the railway company ought to stand one-third of the cost, while the latter deemed that twenty (20) per cent ought to suffice; consequently the decision was left to the author to arbitrate, and his findings were to be adopted as final. The conditions of construction were in a way peculiar, for the cost of most of the substructure would not be increased by widening the superstructure to carry the double-track railway. The reason for this was that the bridge was in the nature of a highway trestle or elevated railroad across rather shallow tidewater, and the smallest pedestals that good practice would sanction had an excess of carrying capacity. The extra cost to the city, therefore, lay mainly in the wider superstructure. The company claimed that as the city intended to pave the railway space so as to permit driving over it, thus nearly doubling the width of wagonway, the city ought to share the expense for the increased width of structure. To this the city officials replied that they really did not need the extra space, but would utilize it if put on; and that the company ought to share in the expense of the substructure. There was also a further complication involved in the swing span. The author decided that the benefit the city would receive from the extra width of roadway would be offset by the free use by the company of the substructure, and that the company's fair share of the expense would be the difference in cost between the combined structure and the one without provision for the railway. Then he made a complete detailed estimate of cost for each case and found that the difference amounted almost exactly to twenty-five (25) per cent of the total cost of the combined structure, and reported accordingly. The decision appeared to satisfy both parties, and the controversy was adjusted in conformity therewith.

When a case of arbitration is left to a single engineer, he is put in a rather awkward predicament, while at the same time the appointment is of a highly complimentary nature. In such a case the arbitrator's fee should be equally paid by the two contestants, in order that he may not be hampered in any way by any false notions of loyalty to either client. The author once conducted a case of this kind, in which an expensive projected city bridge had its estimated cost increased by a railway company which desired to put its tracks beneath the city's structure. The city engineer and the chief engineer of the railway company had agreed upon the extra quantities of materials, but they disagreed about the unit values. As both parties were clients of the arbitrator, he was placed in a most uncomfortable position, nevertheless he managed to satisfy both of them. He handled the matter in this way:

The three engineers met at an informal luncheon with the intention of attending to the business immediately afterward. The arbitrator ex-

plained at the outset that the job was one which he would have avoided if possible, for it might result in converting one or both of his good friends into enemies; but they assured him that there was no danger of that, for they had confidence in his impartiality. He then said that he would conduct the case by taking up each disputed item by itself, hear each engineer's claim, try to get the two into an agreement, and, if unsuccessful, would decide the matter for them, and finally would compute the extra payment for each item and sum up. He warned them that he might have to tread on the toes of one or both parties—and tread hard. The city engineer claimed a difference of \$41,000, and the railway engineer said it should not exceed \$30,000. Following out the programme, each item was adjusted by mutual agreement with almost no coercion on the part of the arbitrator, and the excess cost was found to amount to \$34,500, or \$1,000 less than the average of the two claims. Both parties were perfectly satisfied, and the arbitrator breathed a deep sigh of relief when the matter was concluded.

In settling disputes between the parties building bridges and their contractors, most of the questions at issue are easily decided, if the specifications for the work are thoroughly drawn; although occasionally some point arises where a sense of equity and justice must govern rather than a strict adherence to the letter of the specifications. Every bridge engineer should be broad-minded enough to ignore his own specifications where they would inflict an unforeseen and unjust burden upon a contractor who has done his work faithfully and well but has experienced some hard luck because of having encountered onerous conditions that were not anticipated either by him or by the engineer. Under such circumstances the company's engineer acts as an arbitrator between the company and the contractor, but if either party deems itself aggrieved by any decision, it has the privilege of submitting the matter to an arbitration of three persons, one chosen by each of the two contestants and the third by the two arbitrators thus selected. The decision of the majority of these three arbitrators is supposed to be final, and is nearly always so treated; nevertheless either contestant has the right to carry the dispute to the courts, and this is done on rare occasions. The result, however, generally is that the court supports the arbitrators; and this is as it should be, because in most cases the said arbitrators have acted according to their best judgment, and, as they are trained in the line of work involved, their findings are usually correct.

It is sometimes advisable before inaugurating an arbitration to have each contestant give a bond guaranteeing that he will abide by the decision of the arbitrators. Then if he is dissatisfied with the award, he will still have the privilege of going to law; but to avail himself of it, he will have to sacrifice the bond which he has put up. Such an arrangement will almost invariably result in making the arbitration final.

Occasionally there will arise in an arbitration points of difference that neither the specifications nor equity will settle, and in these the principle of "splitting the difference" is the best method of solution, most reasonable men being willing to adopt it rather than to resort to expensive and long-drawn-out litigation in the courts.

CHAPTER LXXIII

PROMOTION OF BRIDGE PROJECTS

Bridges which are not bought by railroad companies for their own use, or by cities, counties, or townships for public benefit, generally owe their existence to the foresight, energy, and desire for gain of the class of men commonly known as promoters. This designation long ago carried with it some idea of responsibility and high standing (both social and financial) for the individual to whom it was applied; but of late years it has become more a term of reproach than a complimentary appellation. This is due to the fact that America has gradually produced a class of irresponsibles who make their living by their wits through foisting unprofitable ventures upon a credulous public and trading on its natural fondness for gain and the modern desire to get rich quickly. Notwithstanding this unsatisfactory state of affairs, the real, genuine promoter is not a scoundrel, but a public benefactor, in that he labors to inaugurate enterprises which will be both a benefit to the community in general and a legitimate source of profit to those who invest their savings therein. Without the promoter there would be but little progress, and the development of the country would be extremely slow.

The true promoter is the individual who discovers the necessity for some real convenience or utility which will be appreciated by the public to such an extent that people will have to use it and pay adequately for the privilege, who has the ability to convince others of the soundness of his beliefs, and who is gifted with the indefatigability and pluck that will prevent his ever giving up the fight, no matter how great his discouragement. Such a man (and there are indisputably many of them in this country) belongs to the class which is making America great among nations, which is furnishing the people with the wonderful conveniences and luxuries of modern life, and which makes existence a source of pleasure instead of a burden grievous to be borne. All hail, then, to the true promoter, the man of ideas, courage, indefatigability, sound business judgment, and success; and may his days be long in the land!

Promotion work is a high type of salesmanship; and one who is expecting to engage therein would find it to his advantage to study thoroughly the technique of that calling.

Of all the enterprises promulgated by promoters there are but few more worthy than bridge projects; for bridges are a great boon to the traveling public—and in America everybody travels. Moreover, bridge projects are generally a source of profit to those who invest their money

in them (notwithstanding the fact that the free-born American citizen, as a rule, hates to pay toll); for people will travel across the obstruction, if they can, and generally in the quickest way. Wherever there is competition between a bridge and a ferry, the latter, on account of its inferior convenience, sooner or later has to succumb; besides, the bridge tolls can usually be made lower than the ferry charges because of the item of expense of operation, which is far greater for a moving ferry than for a fixed bridge.

Bridge projects may be divided into the following classes, viz., those for

Steam railway traffic,
Electric railway traffic,
Wagon traffic, and
Pedestrian traffic.

Very often, though, two or more kinds of traffic are provided for on the same structure, and in some cases a single bridge will take care of all four kinds. Generally, the more kinds of traffic that are carried the better the enterprise will pay; but there are, of course, exceptions to this rule.

Projects for steam railway bridges are generally inaugurated by groups of wealthy men who see the necessity for carrying one or more lines of railroad across a large river so as to develop a territory as yet unserved by railways. These far-sighted individuals usually take the precaution before investing their money to make provisional contracts for a long term of years with certain roads to use their bridge at certain rates, thus reducing the risk of loss to a minimum. Such an arrangement should always be made, if it be possible, in the inauguration of any railway bridge enterprise.

Electric railway bridge projects are generally combined with those for building the railways, but sometimes they are inaugurated as separate enterprises, mainly with the object of renting to other electric railroads the privilege of using the structure. In some cases the bridge project may appear quite attractive while the railway project does not, and then the only way for the company to get its bridge may be to build it as a separate undertaking.

Wagon bridge projects are evolved in communities where there is urgent necessity for crossing some stream and where people are willing to pay fair tolls for the privilege. Generally it is the duty of the county or city to build such a bridge; but there are localities where the necessary public money is not available and where private capital is. In such cases the building of the structure will be pretty sure to prove a paying venture, especially if the company be granted an exclusive right to bridge the river within certain limits for a certain term of years. Such a monopoly is often difficult to obtain, because it is opposed to the American policy of open competition; nevertheless, when the people of a district

see that there is no other way to secure the desired structure than by granting the exclusive privilege demanded, they will succumb to the inevitable. The promoters then must investigate the state laws with great thoroughness so as to make sure that their charter or franchise is legal; otherwise, after the bridge begins to pay good returns on the investment some other company may succeed in having the old charter declared illegal and in obtaining another to build a rival structure.

Often, though, it is apparent that for many years to come there will be no serious danger from the establishment of a rival bridge project, notwithstanding the fact that almost no good bridge scheme is started without some insignificant imitator trying to raise the money to build a competing structure. Such action is both foolish and reprehensible, for the result of the double attempt is sometimes to kill both projects; and thus the community is left without a much-needed means for transportation. There is no one in the world more timid than a capitalist; and it is often a very simple matter to kill a meritorious enterprise by starting a rival one before the necessary capital is secured; and when once a project has been rejected by bankers of good standing, it is exceedingly difficult for a long time to revive it and raise the requisite funds for its materialization.

Projects for building pedestrian toll-bridges are rather rare, because the conditions calling for them do not often exist. Generally, if there is a demand for the accommodation of pedestrians, there is also a need for that of wagons. The only places suitable for toll structures to carry foot passengers exclusively are those where wide, deep gorges or rivers have to be crossed and where the money is not available for an expensive bridge. In these localities the suspension bridge is generally the most suitable structure, in that it is the cheapest type for long spans to carry light traffic.

The various steps to be taken in the promotion of a bridge project are about as follows:

First. The promoter should investigate personally the possibilities for traffic of all kinds, keeping his own counsel about what he is doing, in order to protect himself from the swarm of blackmailers, leeches, and hold-ups who make a business of fastening themselves upon any one who has the originality to conceive a good enterprise and the courage to undertake it. After finishing this investigation of conditions, he should, if possible, determine what kind or kinds of traffic his bridge ought to provide for and the probable amounts thereof that there will be, both at the outset and for a long series of years.

Second. The next step to take is to go to some reliable bridge specialist, who can be counted upon to treat the matter on a strictly confidential basis, and retain him to make an inspection and survey of the proposed crossing and a preliminary estimate of cost, based upon the data that can be obtained without too great an expenditure of money and without

running much risk of exposing the project to the curiosity of persons who may have rival interests. If this bridge engineer is to be connected with the project throughout its entire materialization, he should be one who has had dealings with bankers and is familiar with their point of view and their attitude toward promoters and new enterprises. Such an engineer could be of much service in making the project presentable.

If the promoter has not been able to make up his mind finally as to the kind of traffic for which he ought to provide, he can now do so with the assistance of his engineer, who will tell him approximately the cost of structure to carry any kind or combination of kinds of traffic, and who will aid him in estimating the probable net revenues therefrom.

Third. After settling the questions of what traffic to provide for, the approximate cost of structure, and the probable net revenue, unless the promoter be a man of great individual wealth, which is extremely improbable, the next step for him to take is to form a company of a few trustworthy friends who possess means to aid him, and have the company take all the necessary legal steps to secure the right to bridge the stream and whatever exclusive privileges it is practicable to obtain.

The formation of a stock company for promotion purposes and to hold title to any assets that may be acquired during that stage of the enterprise has considerable advantage over the partnership form of ownership. The consent of all parties in a partnership is necessary for transferring assets, while in a stock company a majority vote of stock ratifying the action of the Board of Directors is sufficient.

Fourth. Next, the same engineer, or some other one, should be retained to make borings to bed-rock, if there be any at the crossing, or else to a suitable substratum, and from them to determine very closely the cost of structure, based upon current prices of labor and materials, but allowing properly for such contingencies as a possible rise in the material market or an increase in the cost of labor. He should also be required to make a layout to submit to the War Department for approval, if the stream be navigable. These various steps will ensure to the promoter or his company the control of his project from a legal standpoint, which is a *sine qua non* in dealing with capitalists.

Fifth. The next step, and one of the most important, is the preparation of a prospectus. Upon the manner in which this is done will depend the success of the undertaking. The promoter should remember that his project may have to compete with many others for investment-capital and that the demand for this far exceeds the supply; hence his prospectus should be prepared in such a manner as to appeal to the banker from the start and hold his attention in order to win him over and away, perhaps, from other projects that he has under consideration. The requisites for a successful prospectus are honesty, moderation, thoroughness, clearness, conciseness, and a conservative amount of enthusiasm.

Setting aside the moral question involved, honesty is an absolute

essential in preparing the document; for even if it might appear to be advisable to try to deceive others, it would be folly of the worst description to deceive oneself by an unduly favorable statement of the conditions, too low an estimate of first cost or of maintenance, or too high an estimate of revenue.

Moderation is an essential in a prospectus, because bankers are too accustomed to the flights of fancy of the ordinary promoter to be deceived by glittering generalities or rosy-hued statements.

Thoroughness is a necessity, for without it the presentation of the case is incomplete, and its lack will cause serious doubts in the bankers' minds concerning the ability of the interested parties to handle the project.

Clearness is requisite not only to ensure the reader's understanding of what is written, but also to produce a favorable impression on those who hold the purse strings. A well written document invariably carries great weight by means of its correctness of style and its elegance of diction.

Conciseness is necessary, because a busy banker will not take time to wade through a long, verbose statement which shows upon its face the ignorance of its writer concerning this prime requisite of financial documents.

A properly controlled enthusiasm is also an essential for a prospectus; because, unless the promoter is optimistic about his project, nobody else will be; and unless he succeeds in stirring up a certain amount of enthusiasm, his scheme will fail to materialize.

A bridge prospectus should begin by stating as concisely as possible the conditions affecting the business of the proposed structure and the reasons for its location at a certain place. Then it should proceed to give a very short history of the development of the enterprise, and should state who are the principal parties in interest and their standing in the community. The name of the company's engineer should be given, because a banker's action in accepting or rejecting a proposition is often dependent upon who is the engineer retained by the promoters. The company, too, should be fully described, and the amount of its capital stock should be stated. Next should come a short description of the structure with a complete detailed estimate of its cost, immediately following which there should be a statement of the amount of actual cash required for the enterprise, including a certain sum to put the company upon an assured basis of operation for a year or two after the bridge is completed. Next should come a detailed estimate of annual cost of operation, maintenance, depreciation, repairs, interest, taxes, and all other items of expense. This should be prepared by one who is conversant with every detail of the management of such an enterprise and of the cost of operation; for the figures given will have to be verified by the bankers' experts before any contract will be entered into to underwrite the bonds or to furnish the necessary capital. Next there should be given a conservative estimate of revenue, complete and reliable, based

upon premises which are indisputable, and prepared in a manner that is beyond adverse criticism. Following this will naturally come the statement of the estimated net revenue of the enterprise and the probable profits to the stockholders of the company. In concluding a prospectus it is well to give a succinct résumé of the preceding statements and calculations and a concise presentation of the reasons why the project is sure to prove profitable to the investor. If the prospectus is a lengthy one, it is advisable to precede it with a short synopsis, in which should be stated very concisely the *raison d'être* of the enterprise and what it is expected to accomplish. The object of such a synopsis, of course, is to catch quickly the capitalist's attention and arouse his interest—at least sufficiently to induce him to read the whole prospectus. The importance of such a synopsis, if it be judiciously prepared, cannot well be exaggerated.

Sixth. The next step to take is for the promoter (and possibly some other influential member or members of the company) to call on bankers to submit the prospectus, maps, drawings, and other data of interest. It is often well to have the engineer accompany the party, which, by the way, should seldom be large, because a small committee can, as a rule, do business much more expeditiously than a large one. Care is needed in choosing the bankers first to be approached. They should be capitalists who are accustomed to handling bridge projects, and who are not at the time too busy in financing other schemes. Again, the size of the enterprise should aid in determining the bankers first to be interviewed, for certain capitalists deal only with very large projects, others take up those of moderate size, while many are of necessity concerned solely with small ones.

It is almost an essential that the parties in interest go to the bankers well introduced; for often capitalists refuse to receive strangers. Unfortunately, this introduction occasionally costs either the promise of a block of stock or some other recognition of services that involves the expenditure of some of the promoter's money. One seldom gets anything of value for nothing; hence the promoter must not feel disappointed when he finds that an introduction to the financial powers is expensive. It is well, though, for him to make such a remuneration conditional upon the bankers' undertaking the financing of the project, thus reducing the transaction to a perfectly legitimate one of brokerage.

In dealing with bankers the promoter should occupy as little of their time as possible. They are busy men and cannot afford to waste many minutes of their working hours. When the promoter has said his say, let him leave his prospectus and papers, ask for and make another appointment, and bid the capitalists good day. If he fails to remember this hint, he will very quickly be given his *congé* more or less politely; consequently it is just as well to avoid such an unpleasant experience.

The inexperienced promoter almost invariably goes to the capitalists with great notions of how he will handle the deal, how he will lay down

the law to them and permit them to join forces with him in his important undertaking, and how he will concede to them a small percentage of the capital stock and keep the bulk of it for himself and his associates; but after he has once put through a project, or even has tried to do so and failed, he will have become a sadder but a wiser man. He will find that it is the bankers who dictate terms, because enterprises requiring capital are brought to them every day, and from the numerous ones presented they can pick and choose, and that it is they who will take the lion's share of the capital stock and leave a small percentage for the promoting company. Those who seek capital for an enterprise must go prepared to submit to many disappointments and reverses; for financing of projects is no easy matter. Bankers are difficult men to deal with, and they have the whip hand. Moreover, one cannot count upon their doing what they promise or agree to verbally, until they bind themselves in writing, as some of them make a practice of agreeing verbally to underwrite a project, then, if before confirming the agreement in black and white something more attractive is submitted, they feel at liberty to change their minds. On the other hand, though, if they find that a promoter is trying to deal simultaneously with two sets of bankers or capitalists, they will turn him down with great indignation because of alleged lack of good faith.

Should the first capitalists approached reject a proposition, it is often difficult to induce others to entertain it; and after it has been hawked around for a while among various bankers it might as well be abandoned, because it will have gotten a bad name,—and that is almost certain to kill it. Financiers term such projects "footballs." Of course, the first or even the succeeding bankers approached may not be in position to underwrite the project on account of other business; and in such a case a polite request from the promoter not to mention the fact that he had submitted his scheme to them may prevent any ill effects from the unsuccessful attempt or attempts; but a rejection of a project by prominent bankers on the plea of its being of an unsatisfactory character is generally its death knell, because the leading financiers of the large cities meet often and exchange confidences, and there are close, intimate connections between the banking houses of the principal cities. In order to avoid the danger from publicity of one's project, it might be feasible in some cases to have a mutual friend, or some other disinterested person, interview the banker before he is formally approached and sound him as to whether he would be likely to take an interest in an undertaking along certain general lines, without giving him any information which would enable him to locate the enterprise or to discover the names of the parties interested.

If a banker consent to back a project, he will generally demand an option on it for a few weeks or months in order that he may confer with other bankers and obtain their aid in the underwriting, especially if the undertaking is a large one; for the reason that bankers usually act upon

the old established principle that it is not well for one to carry all his eggs in one basket. They prefer to share both profits and risks with their brother bankers. Moreover, it is easier to dispose of the bonds to the small buyers when the issue is largely divided, especially when it is underwritten in several cities.

Bridge bonds are commonly taken by the underwriters at a rather heavy discount, the price for five (5) per cent bonds being often as low as eighty-five (85) cents on the dollar. In addition they demand as large a share of the stock as they think they can squeeze out of the promoters, and this, as a rule, remains in their hands; for it is their custom to sell the bonds to their clients in small amounts at a price about ten (10) cents on the dollar higher than the underwritten figure, and not to give them any of the stock, if they can avoid doing so.

The amount of the bonded indebtedness is ordinarily made large enough to ensure sufficient actual cash to build the structure complete in all its details and to leave a small amount in the treasury in order to provide for a possible deficit in earnings during the first year or two; but sometimes the financier insists that the promoters buy a certain amount of the stock at a small figure, say twenty-five (25) or thirty (30) cents on the dollar; and thus the amount of the bonded indebtedness is reduced. In the preliminary organization of the company and when making the financial arrangements, it is a wise precaution to provide for a possible future increase of bonded indebtedness as well as for an enlargement of capital stock. The amount of the latter at the outset is arbitrarily fixed, and it is of small importance, as it usually represents nothing but water. However, the ordinary arrangement is to make it equal to the amount of the bonded indebtedness. In most cases all the stock is common, but sometimes a portion of it is preferred. If the prospective net profits are small, the preferred stock is the choice kind; but if they are very high, the common stock is the better, as there is no limit to the profit which it may pay, while the preferred stock carries either a fixed or a maximum rate of interest.

If an engineer acts as a promoter or gives much of his time to aid the promoters in financing, he is entitled to a portion of the stock, unless his services are fully paid for either in cash or by an agreement according to which he secures the future engineering of the designing and construction.

Generally, it is not a good thing for a bridge engineer to make a prac tice of promoting enterprises on his own account. It is far better for him to be retained by the promoters to aid them in their work. The possibilities of large profits and the element of gambling involved in such occupation are very attractive to some minds; but experience shows that the bridge engineer will generally succeed better in the end, if he confines his attention and energies mainly to professional duties and leaves to men of less education the pioneer work of promoting. Nevertheless, there may come occasionally to a bridge engineer an opportunity either

to promote for himself or to aid others in promoting a project of exceptionally fine promise. In such a case, if the engineer be a man of years and of wide experience, it may be advisable for him to undertake the promotion; but before doing so he should call to mind the old proverb that "there's many a slip between the cup and the lip" and try to anticipate the various difficulties, backsets, disappointments, and antagonisms which appear to be almost inevitable in the materialization of great enterprises, then decide whether "the game is worth the candle."

Bridge projects can occasionally be materialized by securing from the state, county, or city a guarantee of the principal and interest of the bonds. This is feasible only when the projected bridge is a great public necessity. In such a case the guarantee is likely to carry with it the proviso that the guarantor will have the privilege, after the expiration of a certain time, of buying the structure either for a certain fixed sum or at a valuation to be made by a commission at the time of purchase. From the financier's standpoint this proviso is an objectionable feature, in that it often makes the bonds more difficult to sell; but in most cases the chance that the guarantor will ever avail himself of the privilege is very small.

It is well for the promoter to keep secret all his financial operations, for he generally has to purchase or condemn right of way; and the moment it is known that he has secured the money for his enterprise, up will go the price of everything that he has to buy. It is well, if possible, to secure in advance of any financial negotiations long time options on desired property and to determine or have waived beforehand all damages to real estate in the vicinity of the proposed structure; but often the promoter is unable to raise the cash required to pay for such options, or he may think that the chance of ultimate success is too small to warrant his spending the money.

The preliminary investigations concerning the probable traffic and other sources of revenue should be made with great care and conservatism. One who is optimistic by nature is prone to overestimate, and no promoter is of any account at all unless he is more or less optimistic; hence he should consider very carefully all uncertain matters connected with the revenue estimates, and should endeavor always to err upon the side of safety. Similarly, in computing the annual cost for maintenance, repairs, and other like expenses, he should be careful to omit no items and to figure each item high enough to be beyond criticism. In the chapter on "Estimates" are given lists of items of both first cost and operating expenses, which will be found quite useful to the promoter of bridge projects.

Some engineers in their estimates of cost and maintenance make a practice of allowing very liberally for contingencies; but to the author this always seems an acknowledgment of weakness or lack of experience; for the list of items in each case should be so complete that not even a

minor item is omitted, and the amount allowed for each item should be just about right. Therefore, if the engineer be experienced, capable, and careful, he may either omit the item of contingencies entirely or may reduce its amount to an insignificant figure. If, as was stated in the chapter on "Estimates," one is going to allow at all for contingencies, it is better to do so in a single item instead of adding a small amount to each item on the list. If the latter method is adopted, the result will too often be an excessive total allowance to cover the element of uncertainty. While the author is of the opinion that it is not good practice for *an engineer* to allow too liberally in an estimate for contingencies, he recognizes the fact that *the non-professional promoter*, when unaided by an engineer, should pursue an entirely different policy, in order to avoid serious future difficulties caused by too small an appropriation.

In trying to obtain any franchise or charter most promoters are prone to make too many rash promises and to agree to give too much free stock for influence and other aid, with the result that sometimes they find it necessary later on to buy back such gift stock at considerable expense. It is good policy to incur as few such obligations as possible and to make it one's invariable practice to put all agreements in writing, so that later on there shall be no quibbling about amounts of payments for services rendered. If a promoter is in the habit of making all agreements in writing, and if any one attempts to blackmail him after a successful promotion, as too often happens, the rascal will find that the promoter's confirmed habit of recording agreements and his own inability to produce a written contract will so militate against him with the judge or jury that he will lose his case and fail totally in his nefarious attempt at extortion.

CHAPTER LXXIV

BRIDGE ENGINEERING FEES

It is a generally conceded fact that the engineering profession on the whole is underpaid, for while the young engineers fresh from the technical schools command larger compensation than the recent graduates in law and medicine, their earnings do not increase proportionately with their accumulated knowledge and experience, so that after one or two decades they fall behind the men of their own age in the other professions. But it is when comparing the earnings of those who have reached the summit of their careers that the engineering profession makes the poorest showing. The leading lawyers, physicians, and surgeons demand and obtain large fees for their services, and there are many of them to be found in the great cities of America; but only a very few prominent engineers earn good salaries or large fees, and the amounts of their compensation fall far below those of the shining lights in the other professions. This is all wrong, because no one has to study more faithfully for his degree or work harder in practice to attain success than the engineer. Moreover, none of the world's work is more important than his, for it is a generally acknowledged fact that the whole progress of humanity depends primarily upon his efforts.

What is the reason for this unsatisfactory state of affairs, and upon whom lies the blame? Possibly it is because engineering has only lately been recognized as one of the learned professions; but it is surely old enough to have developed sufficient influence with the public to obtain proper compensation for its members. As for where the blame lies - there is only one answer to the question, viz., upon the engineers themselves. If an engineer of good standing and education makes a practice of working for a mere pittance, is it likely that people will pay him more than he asks or is accustomed to accepting? Again, the unprofessional competition among engineers, that, alas, is by no means uncommon, is responsible to a great degree for the meagreness of technical men's compensation. Until engineers develop in themselves a love and respect for their profession and a desire to advance it by every legitimate means in their power, the existing unsatisfactory conditions will continue, and the day of good times for engineers in general will continue to remain in the dim and distant future.

But what must each individual engineer do to advance the status of the profession and to raise it to a higher plane in public estimation? The answer is not a difficult one. Let him refuse to lend himself to every

endeavor on the part of his clients or employers to keep down the salaries of his subordinates; but, on the contrary, let him insist upon their compensation being advanced as their experience and the value of their services increase. Let him also refrain from envy and ill-natured remarks when he learns that some other engineer in his own class has received advancement or has secured a large fee; but, on the contrary, let him tender his more fortunate brother hearty congratulations; and when he loses a piece of work in competition let him congratulate the employers upon their having secured such valuable services instead of making some ill-natured, sneering, or derogatory remark. Let him also be on the lookout to advance those of his friends in the profession who are worthy of advancement, by recommending them for positions which he knows are to be filled; and let him always be willing to allow any of his assistants to leave his service when they are offered (or when he can find for them) better compensation than he or his principals can afford to pay. Will such a course of procedure tend to hold back his own advancement while others are pushing ahead? Far from it. On the contrary, it will make him so respected by the community in general that his ultimate advancement will be assured.

Certain bridge engineers have established for themselves schedules of charges, and they try to live up to them; but in many cases they are forced either to vary from them or to lose the work. The following is an average schedule of minimum fees for bridge engineers of established reputation:

For the entire engineering connected with the designing, manufacture, and construction of a large bridge, exclusive of the inspection of metalwork at mills and shops, five (5) per cent of the total contract cost of the completed structure, including substructure, superstructure, and approaches, or five and a half (5.5) per cent if the bridge contain a movable span. This is exclusive of the preliminary study of the crossing and the making of borings.

For plans, specifications, and estimates for a large bridge, three (3) per cent of the estimated total cost of substructure, superstructure, and approaches, based upon current prices of materials and labor, or three and a half (3.5) per cent if the bridge contain a movable span.

For plans, specifications, estimates, checking of shop drawings, and inspection of metalwork at rolling mills and bridge shops for a large bridge, three and one-half (3.5) per cent of the total cost of substructure, superstructure, and approaches, or four (4) per cent if the bridge contain a movable span.

For the field engineering alone of any large bridge, the actual cost of doing the work plus either a fixed sum or a monthly salary.

It almost goes without saying that one must charge higher percentage fees for small structures than for large ones, because many of the expenses are just as high in one case as in the other. It is hard to say where an

engineer should draw the dividing line between large and small structures; because it will depend upon the volume of his business and how high he has climbed the professional ladder. What would be a large bridge for a young engineer would be deemed a small one by another of longer experience and greater practice. The author considers that any ordinary structure costing less than two hundred thousand dollars ($200,000) is so small as to require fees exceeding those he charges for more expensive structures.

For an economic study of a proposed crossing with an estimate of cost of structure, excluding the expense for making borings, one-half (½) of one per cent of the estimated total cost.

For inspection only of superstructure metal at mills and shops, one dollar and twenty-five cents ($1.25) per ton of two thousand (2,000) pounds.

For the same inspection with supervision of loading of metalwork on vessel for ocean transportation, one dollar and fifty cents ($1.50) per ton.

For making of borings to and into bed-rock, the actual cost thereof, plus either a lump sum or a salary commensurate with the amount of personal work involved.

For inspection of and reporting upon old structures, the actual cost plus a lump sum or plus a per diem fee of from fifty (50) to one hundred (100) dollars; or, in the case of a great many bridges to be examined consecutively, thirty (30) cents per lineal foot and all traveling expenses.

For expert testimony, not less than one hundred dollars per day and all expenses (including time spent in traveling), and as much more as the magnitude or importance of the work or the value of the said testimony warrants.

For valuation of and reporting upon an existing bridge, one (1) per cent of its estimated value, unless it be a very large structure, in which case the fee might be materially reduced, with a minimum limit of one-half (½) of one per cent.

For administration in addition to the entire engineering on a bridge (*i.e.*, where the construction is done by day labor or at cost plus either a lump sum or a percentage for profit), the percentage for the engineering fee should be increased about one and a half (1½), the size of the increase depending upon the magnitude of the work, the larger the structure the smaller being the increase.

For advice to clients and to attorneys in law suits the fee must be based upon the amount of the money involved and upon the special value of the said advice, as no hard and fast rule will apply to this class of work.

Similarly, for arbitration the compensation must be adjusted to the size of the construction under discussion and to the amount of money the arbitrator has probably saved for his client.

If a client engages an engineer to prepare standard plans for bridges

and to turn over the said plans to him to use as he may see fit and to utilize on as many structures as he may desire, a much larger charge than the ordinary should be made; because, when an engineer prepares plans for a bridge, no one has a right to use them without the designer's permission for any other structure than the one for which they were drawn. In the author's opinion, the fee in this case should be at least twice as great as that which would be charged were the plans to be used only once. Engineers, for the benefit of the profession, ought to discourage all they can the preparation of such standard bridge plans.

For the designing of a movable span alone, the fee should be much higher than that charged for the designing of ordinary, fixed spans. For a swing bridge the percentage should vary from four (4) to five (5), and for a bascule or vertical lift bridge it should run from five (5) to six (6), and the cost of the substructure should be included when the percentage is applied. The designing and detailing of machinery involve very expensive work, and there is a great deal of machinery required to operate movable spans; besides, the structural metalwork therein is more complicated than that for fixed spans· hence the percentage fee for their designing should be greater.

If a bridge engineer of established reputation is paid a per diem fee for any work, he should seldom make his daily charge less than one hundred dollars ($100) and all expenses, unless he be promised as an inducement the engineering of future construction. Under such circumstances it would be perfectly proper for him to halve his per diem fee. All time spent in traveling for clients should be paid for on the same basis as is time spent on actual work.

When an engineer is retained to do important work like that of securing a valuable charter or concession, and when it is upon his professional standing and reputation that success depends, he should be given other inducements than the standard fees or per diem charges; otherwise he would simply be pulling his client's chestnuts out of the fire. If it is mainly upon his ability and reputation that the success of the attempt depends, he surely should be given an interest in the profits obtained through the concession; and it is perfectly legitimate for him to drive as hard a bargain as he can with his clients under such circumstances.

It is not right or politic for a client to force a bridge engineer to pay out of his fee the expenses of making borings, because there is no telling in advance, even approximately, what such borings will cost. It is far better for the client to let the engineer spend freely whatever money is required to secure all the necessary information concerning bed-rock or other foundation; because, ordinarily, every dollar spent in securing such data involves several dollars saved on the construction. It is perfectly legitimate and proper for an engineer to agree to let his charge for preliminary work be absorbed by the later fee for engineering of construction, in case that the project be a large one; but it is better for both

himself and the profession to avoid doing so, if possible. In general, it may be stated that the more an engineer demands for his services the more highly will he be appreciated by the public. Of course, he may sometimes lose a piece of prospective work by holding up his charges; but eventually he will be the gainer thereby, and he will certainly have the satisfaction of knowing that he has done his share to raise the engineering profession to a higher standard.

There is but one case where it is right and proper for a bridge engineer to cut rates, and that is when his client is a brother engineer or an architect, and when the said client has to pay the consulting fee out of his own compensation. Under these circumstances the lower the consulting engineer makes his charge the more worthily does he act; and it is often eminently proper for him to reduce it to zero. He should beware, though, of falling into a trap in such a case; because occasionally a sharp promoter has been known to endeavor to save a consulting engineer's fee by ordering his own engineer to ask for assistance and advice under the false assumption that it is to be paid for out of the said engineer's salary, which is too often a mere pittance.

CHAPTER LXXV

SOME BUSINESS FEATURES OF BRIDGE ENGINEERING

ALTHOUGH engineering is now acknowledged to be a learned profession, it cannot be denied that there is a great deal of business connected with it; and this is specially true of bridge engineering, both in connection with the client's work and with that of the engineer. It is with the latter that this chapter is concerned.

The organization of a bridge engineer's office and field forces, keeping them continually occupied, and arranging finances so that they are paid adequately and regularly, demand business ability of a high order, and he who does not possess it would do well not to attempt to specialize as a consulting bridge engineer. Again, in soliciting work (which, although unprofessional for a lawyer, is by no means so for an engineer) and in dealing with prospective or actual clients, the bridge engineer must have the ability and *savoir faire* to make a good impression and to let people see that he understands his vocation in every detail from start to finish—and this involves the possession of sound business capacity and judgment.

It is in negotiating with prospective clients who are promoting bridge projects that an engineer most requires business experience; for if he does not exercise firmness and sound judgment in making the preliminary financial arrangements, he may later find himself beaten not only out of his time but also out of considerable cash. Most promoters are impecunious, and hence are likely to try to make a bargain with the consulting engineer for the preliminary work based upon promises of future liberal compensation. It may be all right for the engineer to accede to such a proposed method of doing business; but he should invariably insist upon tying up the parties by a hard-and-fast, written agreement, according to which, in case the project is materialized, he will be retained to do all the engineering thereon at certain fixed fees or for other remuneration. Again, he should make sure that he will not be called upon to put any of his own cash into the affair; but should insist that before starting his operations the parties deposit a certain sum of money to his credit to be drawn upon from time to time as needed to pay his assistants and others for doing the preliminary work. He should also make sure that more money will be forthcoming when the first deposit is nearly but not quite exhausted. If he can secure some personal compensation as the work progresses, let him do so by all means; but he will find that generally the promoters prefer to pay him in the future with other people's money. If the project be a good one, it is sound business for the engi-

neer to risk his personal time in the enterprise; but this is as far as he should go; and before the real engineering work immediately antecedent to the letting of contracts is done, payment therefor should be assured beyond the peradventure of a doubt.

In making a contract with promoters, if they have already formed a company, the agreement should be drawn with it instead of with individuals; and it should always be made binding upon its successors or assigns, for it is a sharp trick sometimes practised to try to repudiate an agreement by selling out nominally to other parties. If the engineer in preparing his written agreement will use the author's little book entitled "Engineering Specifications and Contracts," and will apply properly the directions therein given, he will be able to protect himself adequately against all such tricks.

When a bridge engineer agrees to risk his personal time to aid in the development of an enterprise, he ought to secure a future fee larger than the usual one for the work involved, in order to compensate him for the venture. No reasonable man can object to a demand of this kind. As for the amount of the increase—that would entirely depend upon how much personal time would be likely to be needed for materializing the project and upon the magnitude of the construction. Probably from twenty-five (25) to fifty (50) per cent would suffice for most cases.

Often an engineer is asked to take some of his compensation in securities, and here is where his business judgment comes in; for if he refuses, he is likely to offend his principals, and if he accedes, he runs the risk of having unsalable and valueless paper left on his hands. He must first determine in his own mind how badly the promoters need his aid and whether they have any other engineer in view for the work, then tell them whether he will take any securities, how many, and at what price. Bonds are generally pretty safe to accept, especially at a discount, but it is not these which promoters are in the habit of offering. They prefer to give stock, which is worth ordinarily only a few cents on the dollar until long after the structure is finished and utilized for traffic. If bonds are offered, it is well when accepting them to insist on some stock being thrown in as a bonus.

In all business matters the bridge engineer should endeavor to maintain in every way the dignity of the profession, for instance, by patronizing the best hotels and by spending his money as a gentleman should. Any action on the part of an engineer which savors of the picayunish produces an impression unfavorable not only to him personally but also to his profession.

The manner in which a bridge engineer treats his employees is an excellent indication of his business ability or the lack of it. He should engage only competent assistants, and should pay them all that their services are worth. His best method of securing good men is to take them as they come from the technical schools, train them, and pay them

according to what their services are worth, dropping ruthlessly those who are idle, incompetent, or otherwise undesirable. He should take a strong, personal interest in the welfare, development, and advancement of those assistants who give promise of becoming good engineers, and should aid them in every way that lies in his power. Such a course involves not only good engineering ethics but also good business.

He can save himself and his principal assistant engineers much trouble and the office much expense by selecting with care the recent graduates whom he employs. Their instructors in the technical schools can usually give him a very good idea of their ability, industry, and individual peculiarities; and it is well for him to keep in close touch with the professors of those technical schools from which he draws mainly for assistants.

A bridge engineer should insist strictly on regular attendance of all assistants to their work in both office and field, and should so organize his forces that this *desideratum* will be assured. Each assistant should be made to endeavor at all times to produce the maximum amount of useful daily work of which he is capable. The office work should be so laid out that there will always be some valuable routine occupation ready, in case that the ordinary tasks run short. Such an arrangement assures that nobody's time will be wasted for want of something to do, provided that the head of the office allots properly the routine work to the various subordinates. Working hours for office men should be from 8 A.M. until 5.30 P.M., or 6 P.M. with an hour off for luncheon; but in extremely hot weather and when work is not unusually pressing, a half-holiday on Saturday should be allowed, making the hours for that day from 8 A.M. till 1 P.M.

Each employee should be annually granted a two weeks' vacation on full pay. Every man who labors hard is entitled to a short period of rest each year, in which to recuperate his forces and relax his mental strain. By taking such a vacation he will accomplish more useful work annually than he could by continuous labor. The employer, however, should make sure that the vacation period is spent in relaxation and not on work for some one else or in study.

As a matter of business, it is well to pay office men for overtime at their regular rate of hourly compensation, but from such extra earnings should be deducted the value of any time that may have been lost. On the other hand, it is not advisable to dock a good man's salary because of a little unavoidably lost time, unless there be something due him from overtime. But it is not good business to make a practice of working one's employees overtime; however, occasionally it cannot be avoided, especially when there is a piece of work that has to be finished quickly. One cannot obtain effective labor from tired men, and if a practice be made of having the employees work extra time, they will get into the habit of dawdling during the regular working hours in order to enlarge their monthly earnings by overtime occupation. Every field-man's time should

be fully occupied in attending to his regular, routine work, which should be so laid out for him in writing that there will be no excuse for shirking. As there is a good deal of standing around during construction hours for the field engineer, he should not object to giving some portions of his evenings to routine work, such as making notes in his diary and preparing his reports. There should be no overtime allowed for field engineering work.

It is a wise precaution either to carry accident insurance for one's field forces, or to have it understood in writing that a certain small portion of each one's salary is paid him for the purpose of insuring himself, if he so desires; and that if he does not do so, he will have no claim against his employers because of any accident that may happen to him. An engineer should insure his office outfit against fire for as high a figure as the insurance companies will agree to; and even if he does so and is burned out, he will find that he is decidedly out of pocket after the loss has been settled. One cannot insure records at anything like their value, hence it behooves a bridge engineer to have an office in a building that is truly fire-proof.

It is not a bad plan for a bridge engineer to give two or three of his principal assistants a small interest in the annual profits of the office which are in excess of a certain fixed amount; but the advisability of treating the rank and file of the assistants in the same way is problematical. Owing to the fluctuation in the amount of work in both office and field, a bridge engineer, of necessity, must employ more or less floating draftsmen and inspectors, whose services may be dispensed with at any time; and there is no need to let such men share in the profits of the business.

When bad times strike the bridge engineer, he should not make the mistake of discharging all of his men in order to cut down expenses, but he should evolve routine work to keep his best assistants busy until paying work is resumed. If he does not do this, he will find that when the period of depression has passed, he will be unable to do even a small portion of the work that he could readily secure. During good times he should save and lay aside money for the special purpose of carrying his well-trained men, or a good number of them, through the next period of depression.

It is true economy for a bridge specialist to pay a good price for shop inspection, provided that by so doing he makes sure of obtaining it. Cheap inspection is a cause of endless worry and annoyance; and sometimes it entails serious loss to one's clients. One can ensure the best results by keeping .constantly in his employ several trained inspectors who are accustomed to his methods and who know how to obtain good shopwork from the manufacturers; but the payment of their salaries when they are not employed is a heavy tax on his resources. It is generally cheaper for him to let out his metalwork inspection to a good in-

specting bureau; but the results of this method are seldom perfectly satisfactory. The difficulty that he encounters is that the bureau's men are so accustomed to doing slipshod inspection that no matter how strict and complete his written instructions to the bureau may be, or how high a price he may pay for inspection, it is not in them to do the work as well as he requires it to be done. This is a very unsatisfactory state of affairs, and it is due entirely to the pernicious habit of letting metalwork inspection by competition.

CHAPTER LXXVI

RESPONSIBILITY OF THE BRIDGE ENGINEER

There is no member of society who is called upon to shoulder more responsibility than the civil engineer, and of all the specialties in engineering none involves more than that of bridgework; for the man who designs a bridge is responsible for the life of every one who crosses it from the day it is finished until the day it is taken down. It is true that the older a bridge grows the smaller becomes the designer's moral responsibility for its effectiveness, because the structure is liable to deterioration with age, and the loads to which it is subjected may be so increased as to exceed those for which it was designed by more than good practice allows. In such a case the moral liability of the designer should really be assumed by the engineer who looks after and operates the structure; nevertheless if any accident befall it, the first question asked is, "Who was the designer?" and most of the blame naturally falls on him.

But the responsibility for the safety of the people and the property traversing his bridges is not the only serious one with which the conscience of a bridge engineer is burdened; for he is liable (at least morally) for all the errors and mistakes of his various assistants; he is generally blamed if his structures cost more than he estimated or if they are not completed on time; he is called to account (and very properly) if the contractor does not do his work correctly or give the client his money's worth; he is often censured if any serious accident to men or materials occurs during construction; and he is usually either blamed by the contractor for unnecessary severity or by his client for being too lenient. In truth, a bridge engineer's life "is not a happy one"; nevertheless it has its compensations, for the satisfaction experienced from the successful completion of a great structure built under unusual difficulties offsets much of the mental anxiety caused by heavy responsibilities.

The bridge engineer's responsibilities may be divided into three classes, viz., legal, financial, and moral. The legal ones are more imaginary than real, because the courts would never consider as a criminal an engineer upon whose work a serious accident had occurred, unless it could be proved that it was due to maliciousness on his part, which is practically impossible, as no sane man would wilfully cause an accident which would certainly cast a slur upon his own professional reputation, even if his maliciousness could never be discovered. In case a bridge engineer were blamed for an accident, and the matter were brought to court, no judge or jury would ever suggest punishing him for his fault, because

they would feel that his loss of prestige and the griping of his sorrow and remorse would be far greater punishment than any they could inflict.

Nor is a bridge engineer's financial responsibility much greater than his legal, because generally he is by no means a wealthy man. If there were an accident on his work which was proved to be his fault, or if his designs were bad or his calculations erroneous and his client suffered loss thereby, it would be difficult for the said client to recover from him pecuniary damages, primarily because he would not have the money to pay them unless they were quite small, and secondarily because to err is human, and on that account the judge or jury would consider that the client in choosing his engineer took the precaution to investigate his reputation and that, if any mistake were made in the selection, the client alone was to blame.

But the moral responsibility is the one that counts, and it is far heavier than either of the others could possibly be. What greater punishment can be imagined for a conscientious engineer (and nearly all bridge engineers are such) than to have perpetually overshadowing him the depressing thought that through his ignorance, carelessness, or lack of forethought human lives have been lost and valuable property destroyed! The remainder of his life would not be worth living. Far better for him would it be to go down to death with the other unfortunates on his structure!

That this sentiment is a true one was once proved by a certain bridge engineer who was finishing for another member of the profession the repairs to an old structure which carried the main line of an important railway system across a great river. Finding one of the new wrought-iron counters to be too short and therefore only partly effective, he conceived the idea of lengthening it by placing a riveting forge beneath the short end, heating a portion of the bar, pounding upon the metal and at the same time rotating the turn-buckle, and thus stretching the piece. Accordingly he gave orders to the foreman one night to get everything ready, but not to start the fire until his arrival in the morning. Next day his train was late, and the foreman (becoming impatient) heated the bar, twisted the turn-buckle without pounding the metal, and broke the rod, which stretched and parted as would a piece of molasses candy. The deed was done and the damage had to be repaired with the least possible delay; consequently the engineer and the foreman sat down on the deck and evolved jointly a false turn-buckle which could be manufactured in a near-by town and attached in a crude but effective way without the necessity for falsework—that which had been used for the reconstruction of the bridge having been removed. Unfortunately, this repair work demanded time, and a passenger train was due a few minutes after the design was evolved. The engineer felt confident from his general knowledge of bridge superstructures that the other counter of the pair would do the work of the two, but he could not prove it by figures. It was then up to him to decide whether he would block all traffic on the

railroad for more than twenty-four hours or risk the lives of the passengers in the approaching train. Relying upon his engineering judgment, he adopted the latter course and ordered the foreman and all his men off the bridge, but stood himself by the broken counter until the train had passed, preferring the possibility of death to that of professional disgrace. His decision was justified by the safe passage of the train; and by the next evening the broken piece was repaired. That was more than a quarter of a century ago, and the crude turn-buckle has been doing effective service ever since.

A bridge engineer having much practice employs a large force of assistants who are more or less expert; and it is impossible for him to examine in person every detail of their work and make sure that it is right. The best he can do is to train all his men on general principles and so to organize his forces and their work that only well equipped men will be allowed to do important tasks, and that every design will be checked in detail by an independent computer. Even with the best possible organization minor errors will occur, and it is possible that some of them will not be discovered until they enter the actual construction, or that some money is wasted in the shops by their correction. The question then arises as to who should stand the extra expense involved. Legally it would, perhaps, be the client; but morally it is the engineer. In the few such cases which have arisen in the author's practice he has paid the bills, and has taken the opportunity to lecture severely not only the assistants directly responsible for the errors, but also the whole office force. He has sometimes felt that the moral effect of the practical evidence of the evil of carelessness was worth the expenditure for the repairs or modifications.

In case, however, the amount involved were large (for instance, if a bridge were to fall), and if the engineer were not really to blame, it would be unjust to hold him pecuniarily responsible, because the value of his net compensation is altogether too small to warrant his guaranteeing the work of himself and his assistants. All that his client can expect is that he shall do his level best—if that be not good enough, the fault lies with the client for not having made a better choice when selecting the engineer for the work. This question is treated in a masterly manner by Clarence W. Hubbell, Esq., Chief Engineer of the Philippine Bureau of Public Works; and his findings are discussed editorially in *Engineering News* of April 9, 1914, page 779. Mr. Hubbell says:

"It is obviously impossible to hold the individual engineer financially responsible for mistakes or failures. A single error of judgment on his part may cost more than his entire salary of a lifetime. Nor is it customary in any part of the civilized world to hold a professional man financially responsible. A captain loses his ship but he does not reimburse the owner for the loss, nor does he lose his standing as a captain unless investigation shows him to have been negligent in his duties. The average lawyer must of necessity lose at least fifty per cent of his cases; but he does not reimburse

his clients for their financial loss, even though their cases may have been lost through his ignorance or incompetence. The doctor loses many cases; but he makes no financial reimbursement for his mistakes, though he may lose both prestige and practice if his mistakes are too frequent or too well known. Architects and engineers are required to design fire-proof structures; but no one would think of holding them financially responsible for damages caused by fire."

A question of moral responsibility is likely to arise in the case that an engineer prepares plans and specifications for a client and is not retained to supervise the manufacture and erection. If something goes wrong, the client is apt to cast the blame upon the designer, when generally in reality it should be placed jointly upon the manufacturer and the shop inspector. A case of this kind arose once in an engineer's practice, in which the client asked him to pay for the extra expense of errors which he (the client) deemed due to faulty design, but which the engineer contended were caused by bad shopwork and inefficient inspection. Strictly speaking, it is not right to try to make the designer pay for any such errors, even if the fault apparently be his; and unless the responsibility for the trouble encountered be traced beyond all possible doubt to the design, it would be unjust to load him with the moral responsibility and thus injure his professional standing. There is no way to obviate this difficulty, except for the consulting engineer to refuse to prepare the plans unless he be permitted to supervise the inspection, manufacture, and construction; but as his taking such a stand would be likely to involve the loss of the prospective job, he would naturally be averse to so doing, preferring to run the chance of encountering the anticipated difficulties.

Occasionally a bridge engineer finds it necessary to take issue with his client, either to prevent him from doing some wrong or uneconomic construction or to force him to treat his contractor equitably; and under such circumstances the engineer should stand out for what is right, even if the result be that he must resign his position. Clients have no right to dictate to a bridge engineer as to what materials to employ or what type of design to adopt. The engineer should be allowed to use the best materials that the market affords; and as for the type of construction, he can sometimes give the client a choice of two or more that are within the limits of good practice; but when an effort is made to adopt any type which is unfit, the engineer should not only protest, but should fight the question to the bitter end. The client may offer to absolve the engineer from all responsibility by giving him a statement in writing to that effect, but while he can thus absolve him legally, he cannot do so morally, because the engineer will always, in public opinion, be held responsible for the structure which he has designed and supervised. Occasionally, though, some detail of construction objectionable to the engineer but not of grave importance is forced upon him. In such a case all he can do is to protest in writing against the change and keep several copies of his letter filed in safe places for his future justification. Then, when

trouble comes, he will be able to state in the technical press the history of the transaction and prove that he was not to blame. In extreme cases of this kind it is best for the bridge engineer to resign his position, giving written reasons therefor, and either publish his letter at once in the technical press or keep copies of it for future publication.

While, under ordinary conditions, an engineer has no right to dictate to a contractor as to how his work is to be accomplished, whenever it is evident that some risky expedient is about to be adopted, the engineer should point out to the contractor the danger, and if the latter be obstinate, should warn him in writing, thus throwing the responsibility on him. If the matter is grave enough to jeopardize human lives, the engineer should exercise his authority and forbid further progress until the objectionable expedient is either abandoned or so modified as to avoid the anticipated risk.

It occasionally happens that an engineer's client, either through ignorance or lack of moral principle, attempts to take an unfair advantage of the contractor. In such a case, although the engineer is the client's own employee, he should insist upon the contractor's rights being recognized, even if it imperil his own position; for the engineer is the judge or arbitrator in all such cases, and it is his obligation to see that both parties obtain their just dues. Sometimes such action lays the engineer open to the charge of collusion with the contractor; but the possibility of this eventuality should not prevent him from doing what his conscience tells him is his duty. Often by taking a firm stand he will be able either to persuade or to force his client to do the proper thing. A threat of publicity will often compel an unscrupulous man to abandon an unjust action that he is contemplating. The bridge engineer should certainly be a man of nerve, and should be possessed of considerable force of character, in order to be able to deal properly with all the moral and equity questions that are sure to arise in a great practice.

The responsibility of the bridge engineer which is most recognized by the general public is that of ensuring that his structures are built strictly in accordance with the plans and specifications. To accomplish this is an absolute necessity for a successful professional career; and one should never accept any construction that is not truly first-class, no matter how much worry or grief is involved in obtaining proper work. Most bridge contractors desire to build their structures in a creditable and workmanlike manner; but some of them, when they anticipate losing money on the job, attempt every possible expedient for economizing, regardless of the character of the resulting construction. Under such conditions the bridge engineer will find it necessary to exercise the utmost vigilance, and in his dealings with the contractor to employ all the firmness of character with which nature has endowed him or which his worldly experience has developed.

Occasionally a bridge contract is let to an incompetent contractor or

to one who is unwilling to do the work in accordance with the specifications. In such a case, the engineer should assume the responsibility of taking advantage of the clause provided for such a contingency in every properly written bridge specification, by seizing the contractor's plant, letting the work to other parties, and finishing it at the contractor's expense. But before employing this drastic expedient, he should consult his client's attorney so as to make sure that everything is done in a perfectly legal manner, in order to prevent the contractor from collecting damages later for loss of money or alleged injury to reputation.

In order to forestall the contingency of having an incompetent or dishonest contractor on the work, it is well for the bridge engineer to insert a clause in the specifications compelling the successful bidder to prove that he either has or can readily procure the requisite plant, that he possesses ample funds, that either he has had the necessary experience himself, or has arranged to retain as an assistant some one who has had such experience, and that his reputation for completing work honestly and faithfully is unquestioned. Before letting the contract the engineer should see whether the successful bidder fills all these requirements; and if not, he should assume the responsibility of rejecting the bid. In the case of the builder being a private company or an individual, this difficulty can be avoided by choosing as competitors only contractors who fulfil the conditions; but in the case of public work, everybody is allowed to compete, and the low bidders are often irresponsible, inexperienced, and without proper plant or sufficient funds to buy it or to prosecute the construction in the manner desired.

Engineers should assume the responsibility of refusing to let work at figures either below cost or so small that the profit in them is problematical; because, unless a contractor is making money on a job, he is pretty sure to slight it and to cause serious trouble and delay. A protest of this kind by the engineer is often used as a claim that he is showing favoritism, either through friendship or for a pecuniary consideration; but the dread of such an attack on his character should not prevent him from doing his duty. In taking a step of this kind he knows that he is involving himself in a hard fight, hence let him be careful to go armed with all the evidence necessary to ensure his winning it.

In writing the specifications for a bridge, the engineer should assume all the responsibilities that are rightly his, and should not try to unload any of them upon the contractor. He should have the courage of his convictions, and should prove it by telling in the specifications everything that he knows concerning the conditions that will affect the work, instead of leaving the contractor to ascertain these things for himself. It is a cowardly expedient to dodge responsibility by stating that the correctness of the data furnished is not guaranteed; although, on the other hand, it is right to point out that the said data may not be complete and that the contractor must provide for certain contingencies which

may arise. The author, on more than one occasion, has had clients criticize his specifications because of their being too full and because of his giving the bidders too much information, on the theory that each bidder should examine the ground and get all the needed information for himself. This was suggested for the purpose of avoiding responsibility for the company. The author's answer to any such criticism is that, unless the bidders are furnished with complete information, they will tender high, and the company will spend money unnecessarily in what may after all prove to be an unsuccessful endeavor to dodge responsibility; for in case of litigation the courts generally see that the contractor is given his just due.

No engineer should force a contractor to go into court in order to settle questions and disputes that arise between the company and the contractor. The engineer is the arbiter, and he should not shirk responsibility by refusing to settle disputed points. It is true that, notwithstanding the statement of the specifications to the contrary, he is not necessarily the final arbiter; as the courts have held that any stipulation in a specification which takes away from either party to the contract the right to appeal to the law against the engineer's decision is illegal and therefore void, because it is adverse to public policy, in that its effect is to deprive the courts of their jurisdiction. However, it is found that the courts seldom, if ever, reverse an engineer's decision on a disputed point, unless it be clearly proved that he was actuated by dishonest motives in making it, for both the judge and the jury feel that the engineer knows much more about his own business than they do.

In the event that the lives of the contractor's men are endangered through strikes or threats of any kind, it is the duty of the engineer to see that they are properly protected; and he should not shirk the responsibility of advising his client to call in the aid of government troops whenever he deems such a precaution necessary. When the client's property is endangered in any way, for instance by fire, flood, or mob, the bridge engineer's place is where the danger is greatest; and it is his obligation personally to use every endeavor to save the imperiled possessions, no matter what may be the risk to himself. His duty under these circumstances is analogous to that of an army officer; and he must forget for the time being all personal considerations and devote his entire attention and energy to saving the property confided to his charge. Occasions of this kind are liable to occur in the practice of any bridge engineer, and when they do he must face the danger manfully in order to encourage his workmen and assistants to do their duty. The following little stories will exemplify this statement:

When a certain bridge engineer was a young man, he was in charge, for the contractors, of the construction of a railway bridge across a western river. During the winter falsework had been built across the stream, and in the spring, when the ice went out, large cakes of it lodged against the piles and threatened the work with destruction. The engineer who

had been on the tramway for some time in anticipation of the ice jamming, ordered his men to attach ropes to themselves and to the deck, get down on the lodged ice cakes with axes, and cut them away beneath their feet. No man of them was willing to risk his life in that way until the engineer, seizing an axe and tying a rope around his waist, lowered himself down to the ice, and commenced operations. After watching him a while and seeing that his attempt was successful, some of the men followed his example; and by their united efforts, extended over several hours, the falsework was saved. Not a single pile was lost, but several bents were left considerably out of line.

On another occasion when repairing a truss span that had been severely crippled during a flood, the workmen, fearing that it was about to fall, left the structure and would not return to work upon it until the bridge engineer led the way, nor would they remain upon it without him, consequently he had to stay until it was made temporarily safe by auxiliary timbering.

CHAPTER LXXVII

ETHICS OF BRIDGE ENGINEERING

ETHICS has been well defined as "the science of right conduct, or the body of laws governing the relations between human beings." Although there are a number of elaborate treatises on that subject, there has been no well-considered effort to formulate a working code of ethics for the engineering profession. A few desultory endeavors have been made to codify the laws, but none have been well rounded or successful, consequently the profession has but little in this line to work upon except the "golden rule," which in technical life may be best stated by the expression "endeavor always to do the square deal by everybody."

In this chapter, which is supposed to deal only with the ethics of bridge engineering, but which unavoidably touches upon that of engineering in general, no attempt will be made to formulate a set of rules to govern the actions of bridge engineers or to establish a system of ethics; but the author will merely state in detail his ideas of what the bridge engineer's treatment of others and their treatment of him ought to be, in the hope that his suggestions may prove useful to his professional brethren, and may eventually aid in the establishment of a complete and universally recognized code of ethics for engineers.

Until quite recently, the American Society of Civil Engineers has rather discouraged the inauguration under its auspices of a code of engineering ethics; nevertheless the question of its so doing has come up from time to time, and not very long ago a short and rather incomplete code was adopted. Its restrictions are all covered in the contents of this chapter, which was written as far back as 1907. Any code, to be generally acceptable to the profession and to have any prospect of actual adoption in engineering practice, would have to be essentially different in character from many of those that have been suggested in more or less detail by certain engineers. The engineering profession is not composed of saints nor of mean-spirited hypocrites, who, when struck on one cheek, make a practice of turning the other for another blow, but of courageous, hard-fighting men, who are learning to stand up for their rights, and who will not brook imposition. If the engineering profession were limited to cultured gentlemen, the ideals of these ethical dreamers might be materialized; but, unfortunately, there are all kinds and conditions of engineers (real and so-called), ranging from the broad-gauge consulting engineers and the chief engineers of our principal railways

and manufacturing corporations, trained at college and in the technical schools, to the rodmen or even the roustabouts on surveys; for in this free country of ours any one may call himself a civil engineer, provided he can read and write and has had a little practical experience in a most subordinate capacity on some line of engineering construction. Are these rodmen, roustabouts, highway bridge agents, and others of that ilk to be considered by the engineers at or near the top of the profession as professional brethren and treated with all the courtesy that they would naturally show to their peers? Decidedly not. They should, of course, be treated courteously; but when they have the effrontery, as they sometimes do, to advance their opinions concerning important technical matters in opposition to those of engineers who have an acknowledged right to be considered authorities, they should be relegated to their proper place, even if it require some plain speaking to put them there. Engineers of acknowledged standing should have the privilege of drawing the line somewhere and of saying who are and who are not worthy of being considered in their class. For bridge engineers the best criterion is the question, "Does the man under consideration belong to the national society of civil engineers, and, if so, in what grade?" As every high-class bridge engineer either does or should belong to that society, no hardship will be done if an individual who is not a member thereof in any grade and who poses as an expert bridge engineer when competing for work is refused the consideration due an engineer of generally acknowledged standing.

But some ethical cranks will say, "Engineers ought not to compete for work, for by so doing they will lower the standing of the engineering profession and bring it into disfavor with the public." Such a sentiment as that is mawkish humbug and unworthy the consideration of any live man; for in this rapidly developing country competition in all walks of life is inevitable. If it were suppressed in engineering, the profession would receive a serious backset to its development; because the unscrupulous, the incompetent, and the ignorant practitioners, if sufficiently aggressive (as they certainly are) would secure all the work; and the science of design would soon degenerate into rule-of-thumb practice. It is not unusual in bridge work for the contractor (who often dubs himself an engineer without having any real right whatsoever to that title) to make the claim that he is better posted on bridge designing and construction than the consulting engineer who has made a life study of the subject; and not infrequently he succeeds in impressing this belief on inexperienced and unsophisticated persons who have bridges to build. When a bridge engineer encounters opposition of this kind, he ought to be at liberty to express himself freely concerning the relative standing of true bridge experts and incompetent, ignorant contractors. His doing so is no breach of real engineering ethics.

Again, certain sentimental engineers contend that it is *infra dig.*

for an engineer to patent anything that he discovers or evolves, because it is detrimental to the high standing of the engineering profession and tends to retard progress. Surely "the laborer is worthy of his hire"; and if men in other walks of life have the privilege of patenting their inventions, why should not engineers? To bar them thus would be to put the profession at a disadvantage instead of enhancing its dignity as claimed. Most assuredly, every engineer who evolves anything patentable upon which he can make money by securing exclusive rights to manufacture or use, and who does not avail himself of the privilege which the laws of the country grant, makes a mistake. It is all very well to be generous to one's professional brethren, but it is more important to be just to oneself and to those who are dependent upon one. A great many of our large industries are based upon patents taken out by engineers. Who can imagine the development of the air-brake, the steam turbine, the block-signal systems without the protection and profit afforded by the patent? If the invention must be given to the world without charge, who would spend the years and the fortunes devoted to developing and perfecting machines such as the Curtis turbine? It is a well-defined part of every system of progressive government to protect and encourage the inventor; and in these days the inventor is largely the trained, scientific engineer. If a consensus of opinion among engineers of reputation were taken on this question of patents, the result would certainly be overwhelmingly in favor of the technical man's maintaining his personal rights.

The same sentimental engineers before mentioned contend that one engineer should never criticize another engineer or his work. This is eminently right and proper under some circumstances, but not always. For instance, if a man does something wholly unprofessional or dishonorable, or if his work is of a dangerous character, it would be absurd sentimentality to refrain from criticism merely from notions of ethical propriety—in fact, in some cases it would be most reprehensible.

Again, objections have been raised to an engineer's furnishing information gratis to prospective clients, on the plea that it is ruinous to the profession to do so. This, as a rule, is correct; nevertheless there are occasions when an engineer is able to tie up for himself future engineering work of great magnitude by giving at the outset his services free of charge to the promoters; and he would be foolish if he did not avail himself of such opportunities. At the same time, if he fails to bind the promoters in writing to retain him in case the project materializes, he makes a grave mistake as far as his own interests are concerned, and he does not do his duty by the profession, because he lowers the value of engineering knowledge in the public mind and encourages dishonest practice among promoters at the expense of engineers in general.

Following the lead of other writers on engineering ethics, the author will divide ethics for bridge engineers into the following heads:

1. The duty of the bridge engineer to the profession.
2. The relation of the bridge engineer to his professional brethren.
3. The duty of the bridge engineer to his clients or employers.
4. The duty of the bridge engineer to his employees and theirs to him.
5. The duty of the bridge engineer to his contractors.
6. The duty of the bridge engineer to the public.
7. The duty of the bridge engineer to himself.

Each of these divisions will be considered separately.

The Duty of the Bridge Engineer to the Profession

It is the duty of every bridge engineer at all times to do his utmost to advance the interests of the engineering profession not only by the negative method of refraining from all unprofessional actions but also by the positive one of giving direct aid in many ways. He should exert his utmost efforts to maintain its dignity, to raise its standing in the community, and to enlarge its field of usefulness. He should conform to all of its unwritten but generally accepted rules, should refrain from unfriendly or censorious comments on the profession as a whole or on any of its members, should adopt every legitimate means of adding to the accumulated knowledge of the profession, and should give due credit and deference to his seniors by recognizing readily and plainly what they have done for the science of engineering. He should be absolutely honest in all that he does, whether it be in paying just debts, dealing with subordinates and contractors, preparing specifications and other documents, or making scientific technical investigations. Not only should he be honest, but his life both in public and in private should be above reproach.

He should make a practice of giving to his brother bridge engineers the benefit of all that he discovers, mainly by the writing of books, pamphlets, and addresses, never entertaining for a moment that false, selfish, pseudo-economic notion that what he learns should be hoarded for his own personal benefit only.

He should make a point of seizing every opportunity of aiding to develop the young engineers with whom he is thrown in contact by giving them explanations of difficult points, advice, and other help; and, when asked to do so, he should lecture to engineering students on technical matters that will prove interesting and valuable to them, without making any charge for such services; for it is the bounden duty of every successful engineer to aid the professors of civil engineering by teaching their students concerning practical matters that are not treated in the textbooks and about which the professors are not so well informed as he.

In addition to leading a moral life, the bridge engineer should avoid minor offences against the proprieties and the established customs of engineers, being specially careful not to advertise himself improperly. It is unnecessary to suggest anything about the rejecting of commissions

or bribes of any kind offered him by contractors or other interested parties, except to point out that all such vicious conduct should be well ventilated in the technical press, and that the perpetrators of the attempted fraud should receive no mercy. While it may seem prudish for an engineer to reject such small favors as a proffered cigar, it is best to be on the safe side, and thus give captious critics no opportunity to question the engineer's integrity. Such fastidiousness, however, may be carried to an extreme, as was evidenced once some years ago by a young engineer who stated that the author had tried to bribe him by asking him to luncheon. While no right-minded individual can object to the courtesies usual among gentlemen passing between the contractor and the engineer, there are always evil-minded persons on the lookout to make trouble, hence it is inadvisable for the contractor and the engineer to be seen together any more than is necessary for them to attend to the business which they have in common. The author carries this precaution so far as to make a practice when stopping at a contractor's camp for a meal either to pay for it or else to tip the cook or waiter so liberally as not to leave himself pecuniarily indebted for the courtesy and convenience afforded; and he is very strict about insisting that none of his field men accept similar courtesies from the contractors without returning fully the compliment in some manner.

It is improper for an engineer, unless he has just cause, to speak slightingly of the work or opinion of a brother engineer; and he should never exhibit jealousy of the success of others. He should avoid expressing hastily formed opinions; and, except under unusual circumstances, he should not offer technical advice when it is not solicited.

It is claimed by some that an engineer should never submit plans on approval; and, in the main, the claim is correct, but there are cases in which, when an engineer has to meet the persons interested in a bridge project, it helps him materially to show a sketch of the style of structure he would suggest for the proposed crossing. Under these conditions it is perfectly legitimate for him to prepare and offer such preliminary plans. Again, when trying to convince county commissioners and men of that stamp that it pays to retain a specialist to design and supervise the manufacture and construction of their proposed structure, especially when for reasons of their own they prefer the "good, old-fashioned way of letting bridges," a bridge engineer is sometimes told that they have no means of knowing whether the work can be done for the amount of his estimate, and on that account they are unwilling to bind themselves to pay the engineering fee asked. All that he can then do to secure the engineering work is to offer to prepare the preliminary plans and complete specifications and let the commissioners submit them to bidders for tenders. Then, if the lowest responsible bid is so much in excess of the estimate as to be too high for their means, the commissioners may reject the papers and not pay anything for their preparation. Any bridge

engineer who has the courage to back up his convictions in this manner should not be debarred from doing so for fear of violating some principle of etiquette.

Sometimes engineers are requested to guarantee their estimates; but, except in the type of case just referred to, it is improper to do so, not only because of its lowering the dignity of the profession, but also because it is a very risky thing to do. After an engineer has gone to all the expense incidental to the preparation of plans, inspection of materials, and supervision of at least a portion of the construction, if the foundations assumed prove to be inadequate and the cost of the substructure be materially increased, it would be rather severe punishment for an unavoidable miscalculation of cost if he were deprived of all or even a portion of his fee, especially if, according to contract, he were required in any eventuality to finish the work of supervision.

Sometimes an engineer is asked to give a pecuniary guarantee that a movable bridge of his designing will work properly. His answer to the demand should be a refusal, unless the proposed structure be one on which he controls the patents and claims a royalty. Even then the giving of such a guarantee is a risky thing to do; because, generally, he has no control over the manufacture of the machinery.

Bridge engineers should not enter into competition with each other to the extent of cutting rates, as such action lowers the profession in the eyes of the public, besides tending to keep down the compensation of engineers in general. It is far better to tender standard rates and fight for the work upon the basis of professional standing, excellence of design, and reputation for finishing one's bridges satisfactorily to clients.

Bridge engineers should avoid connecting themselves officially with any scheme or project that is merely of a speculative character, or that is chimerical, or that is not backed by real merit. Of course, if one is offered a retainer to do some work on such a project or to report upon its value, it is not necessary for him to refuse the work and the fee attached, unless he can see that the promoters simply want to use his established reputation as an endorsement of their enterprise. Whether one is willing or not to work on a project of doubtful expediency is more a matter to be solved by personal considerations of professional reputation than it is a question of engineering ethics; nevertheless there are those who claim that the acceptance of a retainer on such a project is a violation of the unwritten code. Again, one must not forget that every project must have a beginning and that many which do not promise well at first are ultimately successful; while, on the other hand, many of those which at the outset appear most roseate prove eventually to be failures.

In regard to the ethics involved in the giving of expert testimony many engineers disagree. Some say that no expert witness should be in the pay of either contestant, but should receive his fee from the court. This method would be ideal; but the established law-customs of America

would have to be overturned before such a radical change could be effected. It seems a shame that such should be the case, because the sight of a number of engineers of good standing all testifying in a legal controversy in the most partisan manner and pledging their reputations as to the correctness of diametrically opposed statements is not very edifying, nor is it conducive to elevating the engineering profession in the esteem of the public. The author makes it his policy to refuse, whenever possible, to give expert evidence; and when he cannot avoid it, he explains in advance to the client that he will tell exactly what he knows or ascertains by investigation, no matter who will be benefited or injured by his testimony—in fact, that he will not be partisan under any consideration. It is hardly necessary to say that he is not very often sought after as an expert witness. Bridge engineers in general might do well to take the same stand on this point, for the reasons that the rôle of expert witness is a difficult one to fill satisfactorily, that it is nearly always attended by considerable grief, that the compensation it brings is too small, and that one makes through it more enemies than friends. As a compromise, one might arrange for a certain fee, fixed in advance, to investigate and report upon the case at issue; then, if the result be unfavorable, drop it permanently, but otherwise (for an additional fee) continue it and give evidence, the decision concerning continuance. however, being left entirely to the engineer.

The bridge engineer should confine himself to either purely professional work or contracting. He should never attempt to do both, although it would be perfectly proper for him to change from one line to the other. This is a case of where "no man can serve two masters." If he is a professional bridge engineer, he will require all work to be done in the best practicable manner consistent with reasonable expense, while if he is a contracting engineer, his object will be to have it done as inexpensively as possible. These two points of view are irreconcilable. It is true that with very broad-gauge men they approach each other more or less closely, but they will never meet; hence, if an engineer is to be thoroughly consistent, he should remain on one or the other side of the fence, and should, under no circumstances, attempt to straddle it. If an engineer is in the bridge-contracting line and at the same time makes plans, specifications, and estimates for clients, he will antagonize the regular consulting engineers, which, to say the least, is bad policy; and if he is a consulting bridge engineer, he will give deep offence to bridge builders, if he ever takes a contract for construction. Moreover, no engineer who attempts both consulting practice and contracting simultaneously will ever be able to secure public confidence to anything like the extent which he would were he to confine his attention to purely professional work.

Once in a while a bridge engineer is asked to give a personal bond guaranteeing his faithfulness and integrity; but it is invariably refused. Such a request is an insult to the engineering profession. No lawyer,

doctor, or clergyman is ever asked for such a guarantee, therefore why should an engineer be? The man who could ask an engineer for such a bond is probably untrustworthy himself, and would not hesitate to work against his employer's interests, if by so doing he could secure personal gain. He does not recognize the high standard of integrity that almost invariably governs the actions of civil engineers.

Bridge engineers are sometimes requested to prepare competitive plans for proposed structures. They should refuse to do so unless they receive a fair compensation for the time and expense involved, and unless they are promised the engineering of the structure if they are the winners in the competition, and unless the judges who are to make the award are competent and honorable men. Otherwise, the result of such a competition is almost certain to be loss of time, money, and temper for most, and probably all, of the competitors, as well as the cheapening of engineers' work and injury to the profession. The author can speak on this point with authority, for in times past he entered several competitions, and although apparently successful, he failed to make more than enough money to cover expenses.

There appears to be some uncertainty in the minds of engineers in general about the propriety of one's utilizing in his business any special professional degrees that he has received. There ought to be no objection raised to his using them on his professional cards. This is done in England, where engineers are prone to look askance at nearly every method of professional advertising. Beyond this the author does not believe in going; for he would not advise employing such degrees in correspondence or in making reports, as the term "Civil Engineer" or "Consulting Engineer" after the signature should suffice. Of course, on the title-page of a technical book, an engineer-author has the privilege of stating all the distinctions that he has ever earned.

THE RELATION OF THE BRIDGE ENGINEER TO HIS PROFESSIONAL BRETHREN

The question of who are to be considered as the bridge engineer's professional brethren has been treated in this chapter already. With the restrictions indicated it is not very difficult to state the principal rules of conduct that should guide a bridge engineer in dealing both with his fellows and with those outside of the pale. When he comes in contact with quacks and charlatans, he should not hesitate an instant about exposing them in as public a manner as possible, and he should refuse to consult with them or to have anything to do with them professionally. They are not worthy of consideration, for to their ignorance, presumption, and dishonesty are due the failure of many worthy enterprises and the destruction of bridges that in the aggregate have cost a vast sum of money. The blame for these failures and disasters has generally been

saddled upon the engineering profession, notwithstanding the fact that the guilty parties were not bridge engineers in any sense of the word. But when dealing with any one who is rightly considered an engineer and whose reputation is sound, the bridge engineer should act with the greatest consideration and courtesy. He should be as careful of the reputations and rights of brother engineers as he is of his own. When called in to examine the work of another engineer he should refuse to do so unless the said engineer agrees to accept him; and if he finds anything about the plans or construction of which he does not approve, he should consult fully with the other engineer so as to give him an opportunity to explain his reasons for designing or building in the manner criticized. In reporting upon the work, the consulting engineer should deal as gently as possible with his brother engineer's faults, and should take pains to call attention to the various good points in the design and construction. While making the report full and thorough in every particular, omitting no matter of importance and stating clearly his objections to every feature of which he cannot approve, he should be careful to humiliate his brother engineer as little as possible.

It goes without saying that one should never try to undermine another engineer so as to secure his position. Such an action would be prejudicial to the general reputation of the engineering profession, besides being undeniably selfish and improper.

No bridge engineer should attempt to take away the employees of a brother practitioner; but, should any of them apply to him for work, before considering such application he should consult with their employer and learn whether it is perfectly agreeable to him to let them go.

No bridge engineer should give an endorsement to an assistant unless he is really worthy of it, no matter what the temptation to do so may be; because such an improper endorsement would deceive his brother engineers and would tend to lower the status of the profession.

No bridge engineer should consider accepting a position already held by another engineer, unless that engineer's resignation or dismissal has already been announced.

It is advisable, although not obligatory, that bridge engineers should adhere pretty closely to their own line of work and not cut into those of others. By so doing they are likely to keep more popular professionally than they would if they made a practice of wandering into neighboring fields of occupation. It is no crime, though, for a specialist to cover more than a single line of work in his practice, especially if he has a partner or partners who are versed in other lines than his.

Whenever a bridge engineer encounters in his practice features of design or construction with which he is not familiar and which are outside of his specialty, he should call in to his assistance the best engineering talent he can secure. If practicable, he should make his client pay for such expert services; but if not, he should pay for them himself. The expert

thus called in, before sending his bill, should ascertain who is to pay it; and, if it be his brother engineer, he should make it as small as he conscientiously can. He ought not to be expected in such a case to work for nothing; but he should not charge for any advice of a general nature which he can give his brother engineer without expense to himself. One should be very chary, however, of asking for assistance for which he cannot pay, as so doing tends toward imposition on good nature.

Ingratitude and forgetfulness of past favors are an indication of an unworthy nature, and as such are a violation of the ethics of engineering. Instances of these objectionable traits are, fortunately, rather rare, although not entirely unknown in the engineering profession.

The Duty of the Bridge Engineer to His Clients or Employers

When a bridge engineer is retained on any work, it is his duty to devote his energies loyally and conscientiously to the interests of his client. Nothing should be allowed to stand in the way of his duty, unless the demands of the client conflict with the engineer's sense of what is right and just. In such a case he should argue the matter with his employer until one or the other is convinced; and if an agreement cannot be reached, the engineer should tender his resignation, for he cannot afford to have his name connected in any way, either directly or indirectly, with anything savoring of fraud or injustice. Usually, when an engineer takes such a firm stand as this, the client will give in and will be persuaded to do what is right. Engineers are sometimes asked to falsify reports and estimates or to give false evidence on the witness stand; but a firm negative to the request will generally effect its withdrawal. If it does not, there is only one thing for the engineer to do, no matter what the cost to himself may be.

A bridge engineer should always insist that the amount of his fee for any work be fixed in advance of his undertaking it. If he is careless enough to fail to do so, he may have either to permit the client to determine the amount or to resort to the courts for collection.

Within the limits set by the demands of honesty and integrity, an engineer cannot be too loyal or too devoted to the interests of his client. He should fight for his client's rights as he would for his own, and should aid him with advice whenever opportunity offers, even if such advice is not solicited. Whenever he sees that his client is about to make a mistake of any kind, he should warn him and should use every possible means to convince him of his error.

Unless it is otherwise agreed upon, the bridge engineer who prepares plans has a right to keep the tracings; but the client is entitled at any time to as many blue-print copies thereof as he may desire, provided he pays the actual cost of making them. Nor has the client a right to build

more than a single structure from a set of plans or permit any one else to do so without giving the engineer additional compensation, unless, perchance, the contract between the parties was so drawn.

A bridge engineer need not consider that his entire time and attention should be given to the work of one client, unless a special agreement was made to that effect; for he should be at liberty to do all the other work he desires, provided that he does not in any way neglect his client's interests.

A bridge engineer should not permit his clients to give directions to any of his employees, as all instructions should be delivered to him directly. This is necessary, not only to ensure the work being done properly, but also to maintain discipline in the engineering force.

It is the duty of every bridge engineer, when preparing specifications for submission to bidders, to furnish them as full data as possible, in order that his client may obtain the lowest possible tenders consistent with the securing of proper construction. This matter is treated at length in another chapter.

A bridge engineer must not take that method of settling difficulties which is easiest for himself, but the one which is best for his client's interests.

If a client has any matter that rightfully he deems should be kept secret, his engineer should not only refrain from speaking of it to any one himself, but he should also prevent all his employees from so doing —if necessary, by threat of dismissal.

In all cases reports should be made with perfect frankness, even though they be displeasing to the client.

The study of true economy in designing and construction, or, in other words, the avoidance of all extravagance, is an important duty of a bridge engineer to his client even if his own personal labor is materially augmented thereby.

No true bridge engineer will ever be persuaded either by contractors or clients to call for bids on a structure upon the basis of the bidders submitting competitive plans, for not only does this method involve an acknowledgment of his technical inferiority to those thus invited to tender, but also it results in procuring for his clients designs which are greatly inferior to the best possible that can be evolved.

The Duty of the Bridge Engineer to His Employees and Theirs to Him

The bridge engineer's duty toward his employees consists mainly in seeing that they are sufficiently compensated for their services, whether they be paid by him or by his clients, that they are invariably treated kindly and courteously, that they are allowed every opportunity to obtain valuable experience, that a personal interest is taken in their welfare and professional advancement, that they are given full credit for all

original or special work which they do, and that when they leave they receive (if they are worthy) good recommendations to aid them in securing other positions. The bridge engineer should encourage his subordinates to join the leading engineering societies, and should direct their technical reading and advise them concerning professional matters, to the end that they may develop to the utmost the best that is in them and make themselves worthy members of the engineering profession.

When issuing orders, the bridge engineer should give them to the engineer in charge and not directly to the draftsmen or underlings; because if he does deal directly with such subordinates, he upsets the routine of the work and breaks up the discipline of his organization. There are times, though, when it is necessary to depart from the observance of this rule, such, for instance, as when the engineer in charge is absent; and then the latter as soon as possible should be told courteously of the direct instructions and the reason why they were so given.

The duty of the employee to the bridge engineer consists mainly in doing his work thoroughly and to the best of his ability, working full time always and overtime when it appears necessary, studying how best to make himself useful to his employer, and acting loyally to him at all times in both word and deed. No subordinate has a right to work during his spare time for other parties in order to increase his income, because all his energies belong to his employer. If he does work thus at night and on Sundays, he will be so tired during office hours that he will not be able to attend properly to his regular duties, and, consequently, his employer will be defrauded. Moreover, his doing such outside work is generally in direct competition with his employer, as it would naturally be brought to the office were it not that the one who wants it done thinks he can obtain it more cheaply from the employee than from the employee's principal. It would be bad policy for a bridge engineer to retain in his service any employee who does outside work in this way.

The Duty of the Bridge Engineer to His Contractors

The treatment of his contractors by a bridge engineer should be courteous but firm, kindly but with dignity, liberally but with strict justice both to them and his clients. He should do all that he can to aid the contractors to finish their work expeditiously and economically, so that they will make a fair profit, providing his principals secure satisfactory construction. He should brook no interference or dictation from contractors, yet should always listen to any of their suggestions when politely made, and should act thereon if, in his opinion, to do so would be good policy. If he can legitimately grant them small favors in respect to payments on account, he should so oblige them, provided that he sees they are in pecuniary difficulties, and provided that he in no way jeopardizes his client's money. In short, he should be their true friend in

every sense of the word without laying himself open to any charge of impropriety. In dealing with all disputed points between his client and the contractors, the bridge engineer should not forget that he is to act in a judicial capacity, and not as a partisan.

The Duty of the Bridge Engineer to the Public

Most engineers neglect their public duties, probably for the reason that they are always extremely busy, but possibly because they are so intensely interested in their professional work that they hate to spend much time on anything else. They should, however, devote at least as much attention to political and social matters as good citizens who belong to other professions usually do—possibly more, for an engineer from his practical training is in position to give sound, valuable advice concerning matters of public policy, and his broad and liberal education ought to make him an interesting member of the social world. It would be too much to ask him to hold public office, for he has not the time to spare; nevertheless, he should be willing to act as adviser on matters of public policy. If engineers were to make a point of doing so, the effect would certainly be to cause the profession to be better known and more highly appreciated by the public.

The Duty of the Bridge Engineer to Himself

In addition to his duties to everybody else, the bridge engineer has duties to himself which he should not neglect. He owes it to himself to make the best of all legitimate opportunities for professional and pecuniary gain, to defend his professional character from all assaults, to maintain his reputation for strict honesty and for the prompt payment of all obligations, to make all who know him recognize that his word is as good as his bond and that a promise once given by him is certain to be fulfilled, to obtain a reputation as a man of science through his technical investigations and, if practicable, also through suitable recognition of his worth by means of scholastic and other honors, and to broaden his general knowledge and experience so as to make himself what is popularly known as an "all-around man."

In concluding this chapter the author desires to repeat the hope that the day is not far distant when the engineering profession will possess a firmly established and complete code of ethics; but he recognizes that it would always be very difficult to enforce the regulations of such a code or to penalize engineers for violations thereof, except in the extreme case of glaring dishonesty, when it would be practicable to punish the guilty person by expulsion from all the technical societies of which he may be a member.

CHAPTER LXXVIII

GENERAL SPECIFICATIONS GOVERNING THE DESIGNING OF THE SUPERSTRUCTURES OF STEEL BRIDGES, TRESTLES, VIADUCTS, AND ELEVATED RAILROADS*

CLASSIFICATION

1. *Classification of Bridges in General*

As regards these specifications, all structures are divided into two general classes, viz., railroad bridges and highway bridges. The designing of these classes will differ mainly in the loadings and in certain limitations of sizes of parts; and although the specifications are written so as to cover both classes, no trouble whatsoever should be experienced by the designer in applying them to any particular class or to any type of structure. Electric railway bridges shall conform to the specifications for highway bridges, except as otherwise provided.

2. *Classification for Highway Bridges*

Highway bridges shall be divided into three classes, viz., Class A, which includes those that are subject to the *continued* application of heavy loads; Class B, which includes those that are subject to the *occasional* application of heavy loads; and Class C, which includes those for ordinary, light traffic. In general, it may be stated that bridges of Class A are for densely populated cities, those of Class B for smaller cities and manufacturing districts, and those of Class C for country roads.

MATERIALS

3. *Metal Portions*

In steel superstructures all the parts besides the ties, foot-planks, and guard-timbers of railway bridges and the flooring, pavement, and footwalk slabs of highway bridges shall be of either medium carbon steel or nickel steel, excepting only that bolts and adjustable members are to be of soft carbon steel and rivets of either soft carbon steel or low nickel steel, and that cast iron may be used for purely ornamental work, lamp-posts, large base plates, and a few minor parts of operating machinery for movable spans.

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* Appended to this chapter is a clause index for the use of those who desire to design bridges according to these specifications.

4. *Timber Portions*

Cross-ties, foot-planks, and guard-timbers of railway bridges, and joists, planks, guard-rails, and paving blocks of highway bridges, also all other timber portions of all bridges, shall be of long-leaf, Southern yellow pine, Douglas fir, Pacific Coast cedar, or other timber which, in the opinion of the Engineers, is equally good and serviceable.

Railway Bridge Floors

5. *Timber Floors*

In railroad bridges the wooden floor shall be so designed as to ensure safety from passing trains for the railroad employees, refuge bays three (3) feet by three (3) feet outside of clearance being provided every one hundred (100) feet for deck spans. The spaces between the ties shall not, in general, be less than five (5) inches nor more than six (6) inches wide. The sizes of the ties shall be such as to give the requisite resistance to bending, under the assumption that the load on one pair of wheels is distributed equally over three ties, the effect of impact being considered.

All ties shall be proportioned by the formula,

$$M = \frac{1}{6} Rbd^2,$$

where M is the greatest bending moment in inch-pounds upon a tie, R is the intensity of working stress in pounds per square inch, b the width of the tie in inches, and d the depth of same in inches.

The net dimensions of timber shall invariably be employed when using the preceding formula.

No tie shall be less than seven (7) or, preferably, eight (8) inches wide, nor less than eight (8) inches deep, nor less than ten (10) feet long, except in the case of elevated railroads, where the length may be reduced to eight (8) feet and the depth to six (6) inches for a spacing of five (5) feet between central planes of longitudinal girders.

Ties shall be dapped to a full and even bearing not less than one-half (½) inch on to the stringers; and each alternate tie shall be secured thereto at each end by a three-quarter (¾) inch hook bolt, having at the hook end a square shank at least two (2) inches long to prevent the bolt from turning.

All timber bolts shall be of soft steel.

Outer guard-timbers shall be 6″ × 8″ laid on flat, dapped one (1) inch on to the ties, and placed so that their inner faces shall be not less than twelve (12) inches nor more than fifteen (15) inches from the gauge-planes of rails.

Where inner guard-timbers are employed, they shall be 6″ × 8″ on flat, dapped one (1) inch on to the ties, and placed so that their outer

faces shall be just five (5) inches from the gauge-planes of rails. Steel rails or heavy steel angles effectively braced and well fastened to the ties are preferable to the inner wooden guard-rails—or the inner guards may be omitted altogether, if so required.

Each timber guard-rail must be bolted to each alternate tie by a three-quarter inch bolt having a cup-washer above and an ordinary washer below. Each guard-timber must be spliced over a tie with a half-and-half joint of at least six (6) inches' lap, through which must pass a three-quarter ($\frac{3}{4}$) inch bolt. Lag-screws may be substituted for the bolts with the written permission of the Engineers.

Guard-rails shall extend over all piers and abutments.

Steel tie-plates shall be used between all rails and ties, and the rails shall be attached to the ties by special screw-bolts and washers, unless the Engineers shall direct otherwise in writing.

6. *Ballasted Floors*

A buckled-plate floor with ties in ballast may be used instead of the wooden floor, in which case the size of the ties may be reduced to $6'' \times 8'' \times 8'$. All buckled-plate floors must be thoroughly drained, so as not to retain water, and the upper surface of the buckled plate must be protected from rusting by a liberal use of the best obtainable preservative coating. A solid timber floor supporting ballast and ties may also be adopted, in which case the timbers are to be creosoted or otherwise treated; and the entire live load, impact load, and dead load of a panel may be assumed to be uniformly distributed over the whole area of the panel that is covered by the ballast. Or a reinforced concrete slab with upturned sides to retain the ballast may be employed.

7. *Trough Floors*

A steel trough floor having a wooden tie in each trough, either with or without ballast, may be substituted for the types previously specified.

8. *Floors on Skew Bridges*

The ends of deck plate-girders and track-stringers of skew railroad bridges at abutments shall be square to the track, unless a ballasted floor be used.

HIGHWAY BRIDGE FLOORS

9. *Timber Floors*

In highway bridges the sizes of the timber joists shall be such as to give the requisite resistance to bending, the effect of impact being considered; but no joist shall be less than three (3) inches wide or twelve (12) inches deep.

As a rule, the depth of a joist shall not exceed four (4) times its width. Otherwise, the joists shall be properly bridged at distances not exceeding eight (8) feet.

They shall be proportioned by the formula given previously for ties.

Joists shall be dapped at least one-half (½) inch upon their bearings, and shall have their tops brought to exact level before the planks are laid thereon.

They shall be spaced not to exceed two (2) feet between centres, shall, preferably, lap by each other so as to extend over the full width of the floor-beam, and shall be separated half an inch, so as to permit the circulation of air. The outside joists, however, shall abut so as to provide flush surfaces from end to end of span.

When steel joists are used, wooden shims, at least four (4) inches deep by six (6) inches wide, shall be effectively bolted to their top flanges through holes therein, or else secured thereto by approved metal clips.

Floor planks for the main roadway shall be at least three (3) inches thick and from eight (8) to ten (10) inches wide, and shall be laid, either transversely or diagonally but never longitudinally, with one-quarter (¼) inch openings. Each plank shall be spiked to each joist on which it rests by two (2) seven (7) inch cut spikes, the holes for which shall be bored in order to avoid splitting the timber, or else by two (2) seven (7) inch wire nails.

Whenever a wearing-floor is used, the lower planks must be planed on the upper side and sized to a uniform thickness, and the wearing-floor must be planed on the lower side so as to ensure a perfect bearing between the upper and the lower layers. The planks of the wearing-floor shall be laid either transversely or diagonally but never longitudinally; and those in the lower floor must always be laid in some other direction than that of the planks of the upper floor.

Floor planks for footwalks shall be at least two (2) inches thick and not much more nor less than six (6) inches wide, and shall be laid with one-half (½) inch openings. Each of the said planks shall be spiked to each joist upon which it rests by two (2) six (6) inch cut spikes, the holes for same being bored, or by two (2) six (6) inch wire nails. The floors of footwalks shall extend to and connect with the floor of the main roadway so as to leave no open spaces anywhere in the bridge floor.

All planks shall be laid with the heart side down.

There shall be a wheel-guard of a scantling not less than four (4) inches by six (6) inches on each side of the roadway to prevent wheel hubs from striking the trusses. It is to be laid on its flat, and blocked up from the floor by shims at least one (1) foot long, six (6) inches wide, and two (2) inches thick, spaced not more than five (5) feet between centres, each shim being spiked to the floor by four (4) four and a half (4½) inch cut spikes. The guard-rails are to be bolted to the floor through the centre of each shim by a three-quarter (¾) inch bolt, which must

also pass through the joist beneath. When the guard-rails are bolted to the wooden hand-rail posts, the bolt-heads are to be countersunk into the guard-rail, so as to make a flush surface on the inner face of same. The joints in the guard-rail are to be lap-joints, at least six (6) inches long, each located symmetrically over the middle of a shim. When a bridge is on a heavy grade, the inner, upper corners of the guard-rails are to be covered with steel angles fastened to the timber by counter-sunk screws, spaced about eighteen (18) inches apart, so as to protect the guard-rails from the injurious effects of using them instead of wheel-brakes for heavily loaded wagons.

When wooden hand-rails are employed, they are to be made of approved timber, the posts being 4″ × 6″ × 4′ 6″ to 5′, with two (2) runs of 2″ × 6″ timbers (one on its flat and the other below on edge to support the first for a hand-rail), one (1) run of 2″ × 12″ hub-plank, and in some cases a run of 2″ × 6″ plank near the floor. The posts are to be spaced not to exceed ten (10) or, preferably, eight (8) feet apart. The hand-railing is to be firmly attached to the bridge and rigidly braced. When the rigidity of a hand-railing is dependent upon that of the outer joists, the latter must be properly bridged and stiffened. Any other wooden hand-railing of equal strength and rigidity, and which is satisfactory to the Engineers, will, however, be accepted.

When iron hand-railing is employed, it is to be of a firm, substantial pattern, pleasing to the eye, and rigidly attached to the trusses or floor-beams. Both through and deck bridges are to be provided with a hand-rail on each side, not less than three and a half (3½) feet high above the floor. In case there be any liability of a horse jumping over this railing, its height must be increased to four and a half (4½) or five (5) feet. There must be a hand-rail on the outside of each sidewalk not less than three and a half (3½) feet in height above the floor.

All floor-timbers, guards, and railings shall extend over all piers and abutments and make suitable connection with the embankments at the ends of the structure. Aprons or cover-joints of steel plate shall be provided at the ends of spans, if required.

10. *Street-Railroad Tracks*

Should there be one or more street-railroad tracks crossing the bridge, there should generally be placed directly under each rail a joist or stringer, properly proportioned to resist the effect of the total maximum load on the rail. The rails shall be so laid as to offer as little obstruction as possible to the wheels of vehicles.

11. *Paved Floors*

Where paved floors are adopted, the pavement shall be the best of its kind, and shall be built according to the latest and most approved speci-

fications. Paved floors are always to be supported by a reinforced concrete base resting on steel stringers, preferably of rolled I-beams, spaced generally not to exceed five (5) feet between centres. The surface of the pavement must be thoroughly drained so as not to retain water.

12. *Superelevation on Curves*

On curves the outer rail must be elevated the proper amount for the degree of curvature and for the assumed medium velocity of trains; and this elevation must be framed into the ties, or else be provided by raising the outer stringer or girder, and depressing the inner one, if necessary. The formula to be used for total superelevation on standard-gauge roads is

$$E = \frac{4V^2}{R};$$

where E is the total superelevation in inches of the exterior rail above the interior rail, V is the assumed medium velocity of train in miles per hour, and R is the radius of the curve in feet.

The assumed medium velocity of the train in miles per hour shall be taken at

$$V = 42 - 1.75D;$$

where V = speed in miles per hour,
and D = degree of curvature.
The total superelevation is to be obtained by elevating the outer rail and keeping the inner rail at grade. The run-ups on the tangents at ends of curves are to be not less than forty (40) feet long for each inch of superelevation.

In Fig. 8*a* are given the superelevations required for curves up to twenty (20) degrees.

13. *Rerailing Apparatus*

Unless the Engineers give written permission to the contrary, at each end of every bridge or trestle there is to be placed a rerailing apparatus that will, in the most effective manner practicable, return to the track any derailed car or locomotive that is not more than half the width of track gauge out of line.

14. *Spacing of Stringers and Girders in Railway Bridges*

In general, stringers for through-bridges shall be spaced from seven (7) to eight (8) feet centres for single-track bridges and from six (6) feet six (6) inches to seven (7) feet for double-track bridges and half-through plate-girder bridges. In elevated railroads the spacing of the longitudinal girders may be made as small as five (5) feet centres. Single-track, deck plate-girders may be spaced from seven (7) feet to ten (10) feet centres,

the usual distance being the nearest even foot to one-tenth ($^1/_{10}$) of the span; but in high trestles the spacing shall, preferably, be ten (10) feet, and never less than eight (8) feet. Deck plate-girders for multiple-track bridges shall usually be spaced six feet six inches (6′ 6″) from centre to centre. The spacing of half-through plate-girders shall be made as small as the clearance requirements will permit.

When there are four (4) lines of I-beams per track in short spans or in floor systems of other spans, the beams carrying each rail shall be placed symmetrically about the centre line of the said rail and not less than fifteen (15) inches from centre to centre.

15. *Spacing of Trusses in Railway Bridges*

From centre to centre of through trusses the perpendicular distance shall not be less than seventeen (17) feet, or one-twentieth ($^1/_{20}$) of the span length.

From centre to centre of deck pin-connected or open-webbed riveted trusses the said perpendicular distance shall not be less than that given in the following table, except in the case of elevated railroads where open-webbed, riveted girders are adopted, in which case they may be spaced according to the directions given for plate-girders.

TABLE 78*a*

SPACING OF TRUSSES IN RAILWAY DECK BRIDGES

Span Length, in Feet	Ratio of Perpendicular Distance between Central Planes of Trusses to Span Length.
150	One-thirteenth ($^1/_{13}$)
200	One-fourteenth ($^1/_{14}$)
300	One-fifteenth ($^1/_{15}$)
400	One-sixteenth ($^1/_{16}$)
500	One-seventeenth ($^1/_{17}$)
600 and over	One-eighteenth ($^1/_{18}$)

16. *Clearances for Railway Bridges*

In single-track, steam-railway bridges the clear opening on tangent shall not be less than that shown in Fig. 22*ii*. This diagram will suffice for double-track bridges also by increasing the horizontal clearance to 28 feet, when the distance from centre to centre of tracks is thirteen (13) feet, or to correspondingly greater widths for greater distances.

On curved track, the horizontal distance from the centre of track to clearance line shall be increased thus:

Single-track through bridges on curves shall have the location of the trusses or girders and the width between clearance lines as shown in Figs. 8*e* and 8*f*. In these diagrams,

W = the lateral clearance from the centre line of track required for tangent alignment.

M = the middle ordinate of the curve for a chord equal to the span length.

X = an addition for the overhang of a car 85 feet long and 60 feet from centre to centre of trucks, to be taken as 1 inch for each degree of curve.

Y = an addition in inches (on the inside of the curve only) on account of the superelevation of the outer rail, to be taken as follows:

$$Y = \frac{sh}{5}, \text{ but not more than } 3s,$$

where s = superelevation in inches,

and h = height of top of car above base of rail in feet.

For double-track bridges the increase between clearance lines shall be effected as just explained for the case of structures on tangent.

17. *Clearances for Highway Bridges*

The smallest allowable clear roadway shall be twenty (20) feet, measured between curb lines, with ten (10) feet extra for each additional line of traffic, excepting for cheap county bridges, where it may be reduced to eighteen (18) feet, or even to fourteen (14) feet when the bridge is so short that no provision need be made for teams passing thereon.

The smallest allowable clear headway shall be sixteen (16) feet, except for bridges in cities where the ordinances require a greater height, or for bridges carrying electric railway tracks, in which structures the vertical clearance should be, preferably, twenty (20) feet. The corner-brackets may, however, encroach on the specified clear headway, provided they do not extend either laterally or downward more than five (5) feet.

18. *Spacing of Tracks*

Steam railway tracks shall usually be spaced thirteen (13) feet from centre to centre and electric railway tracks ten (10) feet or more from centre to centre, with a proper increase for sharp curvature.

19. *Effective Lengths*

For pin-connected or riveted trusses the effective length shall be the distance between centres of end-pins.

For plate or open-webbed riveted girders it shall be either the distance between centres of bearing-plates or that between centres of pedestal pins.

For stringers it shall be the distance between centres of cross-girder webs.

For cross-girders it shall be the perpendicular distance between central planes of trusses or girders.

For columns and posts it shall be the greatest length between points of axis that are rigidly held in the direction in which the strength is being considered.

20. *Effective Depths*

Effective depths shall be as follows:

For both pin-connected and riveted trusses, the perpendicular distance between gravity lines of chords (which must coincide with pin centres).

For plate-girders and open-webbed riveted girders, the perpendicular distance between centre lines of gravity of upper and lower flanges, but never greater than the distance out to out of flange angles.

21. *Styles of Railway Bridges for Various Span Lengths*

For spans under twenty-five (25) or thirty (30) feet, rolled I-beams.

For spans between twenty-five (25) or thirty (30) feet and one hundred and ten (110) feet, plate-girders.

For spans between one hundred and ten (110) feet and three hundred and fifty (350) feet, riveted trusses of single cancellation.

For spans exceeding three hundred and fifty (350) feet, pin-connected or riveted trusses with subdivided panels.

The use of pony-truss bridges of any kind is prohibited, excepting only half-through, plate-girder spans, in which the top flanges are held rigidly in place by brackets riveted to cross-girders that are spaced not to exceed twelve (12) times the width of the top flange.

In general, double-track truss-bridges shall have only two trusses, in order to avoid spreading the tracks.

22. *Styles of Highway Bridges for Various Span Lengths*

In general, spans of and below twenty (20) feet are to consist of rolled beams or simply wooden joists; spans from twenty (20) to thirty (30) feet of rolled beams; spans from thirty (30) to sixty (60) feet of plate-girders; spans from sixty (60) to one hundred (100) feet of plate-girders or open-webbed riveted girders of single cancellation; spans from one hundred (100) to three hundred (300) feet of riveted trusses; and spans exceeding three hundred (300) feet of pin-connected or riveted trusses.

The use of pony-truss bridges of any kind is discouraged, excepting only half-through, plate-girder spans, in which the top flanges are held rigidly in place by brackets riveted to cross-girders that are spaced generally not to exceed twelve (12) times the width of the top flange.

23. *Forms of Trusses for Railway Bridges*

The forms of trusses to be used are as follows:

For deck-spans having top chords supporting wooden ties, the War-

ren or the Triangular truss with verticals dividing the panels of the top chords.

For other deck-spans and through spans, up to three hundred (300) feet, the Pratt truss.

For spans exceeding three hundred (300) feet, the Petit truss.

For through spans up to about two hundred (200) feet parallel chords are to be employed; but for longer spans the top chords are generally to be made polygonal.

It is understood that these limiting lengths are not fixed absolutely, as the best limits will vary somewhat with the number of tracks and the weight of trains.

24. *Forms of Trusses for Highway Bridges*

The forms of trusses to be used are as follows:

For open-webbed, riveted girders the Pratt truss, or the Warren or the Triangular truss with verticals dividing the panels, the latter being employed for deck spans carrying joists resting on the top chords.

For riveted spans up to about two hundred and fifty (250) feet, Pratt trusses with top chords either straight or polygonal.

For spans exceeding two hundred and fifty (250) feet, Petit trusses.

It is understood that these limiting lengths are not fixed absolutely, as the best limits will vary somewhat with the width of bridge and the live load to be carried.

25. *Main Members of Railway Truss-Bridges*

All spans of every kind shall have end as well as intermediate floor-beams, riveted rigidly to the trusses or girders, for supporting the stringers. The latter are to be riveted to the webs of the cross-girders, and shelf angles shall be provided to support them during erection; but the rivets attaching the said angles are not to be counted upon to carry the stringer or its load. In general, all trusses shall have main end posts inclined. All trusses shall be so designed as to admit of accurate calculation of all stresses, excepting only such unimportant cases of ambiguity as that involved by using two stiff diagonals in a middle panel. Counterbracing shall be effected by using stiff diagonals, as no adjustable truss members will be permitted.

All lateral bracing and other sway-bracing shall, preferably, be rigid both above and below, *i.e.*, the sections must be capable of resisting compression, adjustable rods for such bracing not being allowed under any circumstances. The stiff diagonals of lateral systems in the plane of the loaded chords, which systems are generally to be of double cancellation, shall be riveted rigidly to each other where they intersect and, if practicable, to the stringers where they cross them, and shall be braced apart so as to transfer in an effective manner the thrust of braked trains

to the truss-posts without causing a horizontal bending on either the cross-girders or the diagonals.

All through-spans shall have stiff portal bracing at each end, properly designed to resist the greatest wind stresses and rigidly connected to both flanges of the inclined end posts. The said portal bracing shall be made as deep as the specified clear headroom will allow. When the height of the trusses is great enough to permit it, there shall be used at each panel point a rigid bracing frame riveted to the top lateral strut and to the posts, and carried down to the clearance line. When the truss depth is not great enough for this detail, corner brackets of proper size, strength, and rigidity are to be riveted between the posts and the upper lateral struts.

Deck-bridges shall have stiff diagonal braces between opposite vertical posts, figured to carry across safely a shear equal to one-half of a panel truss live load with its impact allowance; and the transverse bracing between the vertical or inclined posts at each end shall be sufficiently strong to transmit properly to the masonry one-half of the wind-pressure (and centrifugal load, if there be any) which is carried by the entire upper lateral system of the span.

In pin-connected structures the suspenders, the hip verticals, and two or more panel lengths of bottom chord at each end of each span shall be made rigid members.

All floor-beams in truss spans are to be riveted to the truss-posts or built hangers.

26. *Main Members of Highway Truss-Bridges*

All spans of every kind shall have end as well as intermediate floor-beams, riveted rigidly to the trusses or girders, for supporting the joists or stringers. Steel stringers are, preferably, to be riveted to the webs of the cross-girders, but wooden joists are generally to rest on top of the latter. In general, all trusses shall have main end posts inclined. All trusses shall be so designed as to admit of accurate calculations of all stresses, excepting only such unimportant cases of ambiguity as occur when two stiff diagonals are used in a middle panel.

In the trusses of important bridges counterbracing the web shall be effected by using stiff diagonals, but in cheap bridges it may be done by employing counters of adjustable rods.

In important bridges with steel stringers, all lateral bracing and other sway-bracing shall, preferably, be rigid above and below, *i.e.*, the sections should be capable of resisting compression, adjustable rods for such bracing being allowed only in towers of draw-spans and in the lower lateral systems of deck bridges; but in cheap county bridges the lateral and other sway diagonals may be adjustable rods. The stiff diagonals of lateral systems in the plane of the loaded chords, which systems are generally to be of double cancellation, shall be riveted rigidly to each

other where they intersect and, if practicable, to all the steel stringers where they cross them.

All through-spans shall have portal bracing at each end, properly designed to resist the greatest wind stresses, and carried as low as the specified clear headroom will allow. The portal struts and diagonals shall be riveted rigidly to both flanges of the inclined end posts. When the height of the trusses is great enough to permit it, transverse, vertical sway-bracing shall be employed at each panel point; otherwise, corner brackets of proper size, strength, and rigidity are to be riveted between the posts and the upper lateral struts.

Deck-bridges shall have sway-diagonals between opposite vertical posts of sufficient strength to carry one-half of a panel truss live load with its impact allowance; and the transverse bracing between the vertical or inclined posts at each end of span shall be sufficiently strong to transmit properly to the masonry one-half of the total wind-pressure (and the centrifugal load for spans with electric-railway tracks on curve) carried by the upper lateral system of the span.

In important, pin-connected bridges, the suspenders, the hip verticals, and two or more panel lengths of bottom chord at each end of span shall be made rigid members.

All floor-beams are to be riveted to the truss-posts in truss-spans, excepting in the case that eye-bars be used for suspenders or hip verticals. In such cases floor-beam hangers may be used, provided they be made of plates or shapes and that they be stayed at their upper ends against all possibility of rotation.

27. *Continuous Spans*

Except in the case of swing-bridges or cantilevers, consecutive spans are not to be made continuous over the points of support.

28. *Railway Trestles*

As a general rule, each trestle-bent shall be composed of two columns battered from one and a half (1½) to two and a half (2½) inches or more to the foot, the bents being united in pairs to form towers. Each tower thus formed shall be thoroughly sway-braced with struts on all four faces, and shall have four (4) horizontal struts at the base and four (4) more in each horizontal division plane of the tower bracing. In trestles of moderate height it is permissible to adopt from one (1) to three (3) or even four (4) solitary bents between the braced towers, which bents may or may not have rocker ends.

The feet of the columns must be attached to anchorages capable of resisting twice the greatest possible uplifting; and the details of the metalwork connecting the anchor-rods to the columns must be such as to make the metalwork and pedestals act as a single piece, so that, if

tested to destruction by overturning, the bent would not fail in the vicinity of the base. While it is desirable to have sufficient base to prevent any tension from coming on the anchor-bolts, it is not advisable on this account to make the batter of the columns too great, especially in very high trestles. When trestle-bents become unduly wide, a vertical column is to be placed midway between the legs as so to divide up the transverse sway-bracing. Care must be taken to provide properly for expansion and contraction at column feet both transversely and longitudinally.

In elevated railroads and trestles of small height, the towers can be placed at about every fourth span or, say, every one hundred and fifty feet, or can be dispensed with altogether, when the conditions so require, by strengthening the columns properly to resist traction, thrust of braked trains, and the longitudinal component of diagonal wind-pressure.

Longitudinal girders shall generally consist of deck plate-girders for spans less than one hundred and ten (110) feet in length and deck riveted-trusses for longer spans.

29. *Highway Trestles*

In general, the specifications for railway trestles are to be followed in designing highway trestles or viaducts, except that in cheap structures all sway-diagonals of towers may be made of adjustable rods, with horizontal struts at the panel points, provided that the struts be rigidly riveted to the columns.

30. *Camber*

All trusses must be provided with such a camber that, with half of full live-plus-impact load over the entire span, the total camber shall be taken out by deflection. The actual deformations of the various members under dead load plus half live-plus-impact load should be computed; and the tension members should then be fabricated shorter and the compression members longer than their lengths under the above loads, by the amounts of the computed deformations. The camber of the truss in the unloaded condition should then be figured. In railway floors, one-half of the camber after a span is swung may be taken out of the track by dapping the ties, unless this would cut too deeply into the timber. Plate girders and shallow, open-webbed, riveted girders are not to be given any camber. In calculating deformations the gross areas of all members are to be used.

Approximate methods of figuring camber may be used for short, simple-span trusses.

31. *Expansion*

Every span must be provided with some means of longitudinal expansion and contraction due to changes of temperature over a range of one hundred and fifty (150) degrees Fahrenheit in very cold climates and ninety (90) degrees in tropical ones, combined with the greatest extension of bottom chords due to live load and impact.

Spans up to fifty (50) feet in length may slide on planed surfaces; but those of greater length must move on nests of turned rollers and must have rocker bearings.

32. *Anchorage*

Every span must be anchored at each end to the pier or abutment in such a manner as to prevent the slightest lateral motion, but so as not to interfere with the longitudinal motion of the trusses or girders due to changes of temperature or of loading. All bearings shall be secured to the masonry by fox-bolts not less than one and a quarter (1¼) inches in diameter for girder spans or one and a half (1½) inches for truss spans. When the structure is subject to possible uplift, anchor bolts, effectively attached to the superstructure, shall engage a mass of masonry, the weight of which is at least twice the greatest possible uplift.

33. *Name-Plates*

Name-plates having thereon the names of the designer, manufacturer, and builder and the date of erection must be attached in a durable manner and in a prominent position to every bridge and trestle.

LOADS

34. *Loads for Railway Bridges*

Bridges, trestles, and elevated railroads are to be designed to sustain properly the greatest stresses produced in them by any of the following loads or by any combination of them which may reasonably be expected to occur.

A. Live Load.
B. Impact Load.
C. Dead Load.
D. Uplift Load (for swing spans only).
E. Direct Wind Load.
F. Indirect Wind Load or Transferred Load.
G. Vibration Load.
H. Traction Load.
I. Centrifugal Load.
J. Effects of Changes of Temperature.

35. *Loads for Highway Bridges*

The loads to be considered in designing highway bridges and trestles are the following; and all parts of such structures are to be proportioned to sustain properly the greatest stresses produced thereby for all reasonable combinations of the various loads, excepting only that the live load and the wind load cannot act together, unless the structure carry an elec-

tric railway; for the reason that no person would venture on the bridge when even one-half of the assumed wind-pressure is acting.

A. Live Load.
B. Impact Load.
C. Dead Load.
D. Uplift Load (for swing spans only).
E. Direct Wind Load.
F. Indirect Wind Load or Transferred Load.
G. Effects of Changes of Temperature.

When a highway bridge carries an electric railway, it shall be proportioned also for—

H. Traction Load, and
I. Centrifugal Load.

36. *Live Loads for Railway Bridges*

The live loads to be used in designing any railroad structure shall be taken from Figs. 6*b*, 6*c*, 6*d*, and 6*e*.

In single-track bridges only one of the live loads there given can be used for any span; but in bridges having more than one track two or even three classes of loading may be employed to advantage in the same span; for instance, a certain heavy load could be used for the stringers, the next lighter load for the floor-beams, and a still lighter load for the trusses, thus utilizing the theory of probabilities.

For elevated railroads and for the bridges of electric railways the live loads are to be taken from Figs. 6*f* to 6*n*, inclusive.

The equivalent live loads given in the diagrams of Figs. 6*c*, 6*d*, 6*e*, and 6*g* to 6*n* inclusive are to be used in making stress computations instead of the actual wheel concentrations.

In applying these curves, the span-lengths used shall be as follows:

For stringers, a single-panel length; for floor-beams and single-panel suspenders with their corresponding secondary truss struts, two (2) panel lengths; for hip verticals of Petit trusses, four (4) panel lengths; and for all main truss-members, the length of span.

In calculating the stresses caused by a uniform moving load, the said load shall be assumed to cover the panel in advance of the panel point considered; but the half-panel load going to the forward panel point will be ignored; or, in other words, the uniform load will be treated as if concentrated at the various panel points.

In deck-spans on sharp curves, after the centre curve for each rail and the centre lines of the longitudinal girders are laid out, the approximate extra live load, if any, on the outer girder due to the projection of the curve of the rail beyond its centre line near mid-span is to be computed and added to the regular live load; but the corresponding excess of dead load from the flooring, being small, is to be ignored. As the

superelevation provides for an equal distribution of the live load on the rails for the assumed medium velocity of trains, there will be an excess of live load on the outer girder due to the velocity being sometimes greater than this. The excess of live load on the inner girder, due to the velocity of train being sometimes less than that assumed for determining the superelevation, is offset by the fact that the impact is then reduced; hence it is to be ignored.

37. *Live Loads for Highway Bridges*

The uniformly distributed live loads per square foot of floor, including the entire clear widths of both main roadway and footwalks, shall be taken from the curve diagram shown in Fig. 6*o*; and the concentrated live loads shall be taken from Fig. 6*p*. In applying the curves, the span-lengths used shall be as follows:

For stringers and joists, a single panel length; for floor-beams and single-panel suspenders with their corresponding secondary truss struts, two (2) panel lengths; for hip verticals of Petit trusses, four (4) panel lengths; and for all main truss-members, the length of span.

In the case of bridges with exterior sidewalks, one sidewalk only and the roadway are to be considered loaded when proportioning the beam-hangers and secondary truss members of all bridges, and when proportioning the main truss-members of all spans of less than one hundred (100) feet for bridges of Class A, and of all spans of less than eighty (80) feet for bridges of Classes B and C. In all other cases both of the sidewalks and the roadway are to be considered loaded. The eccentric loading increases the live load per truss. But, when a bridge has only one exterior sidewalk, the effect of the eccentric loading is to be considered to act upon the whole of the nearer truss, and the sidewalk is to be considered empty when calculating the stresses in the farther truss. Floor-beams of bridges with one or two exterior sidewalks are to be proportioned on the assumption that, first, the main roadway is loaded and the sidewalk or sidewalks are empty; and, second, that the main roadway is empty and the sidewalk or sidewalks are loaded, due account being taken of the effect of reversing stresses as hereinafter specified.

As in the case of railway bridges, in calculating the stresses caused by a uniform moving load, the said load shall be assumed to cover the panel in advance of the panel point considered; but the half-panel load going to the forward panel point will be ignored; or, in other words, the uniform load will be treated as if concentrated at the various panel points.

The concentrated live loads given in Fig. 6*p* are to apply only to the flooring, joists, floor-beams, and secondary truss members. They are supposed to occupy a whole panel length of the main roadway to the exclusion of the other live loads there (excepting only the electric railway live

load). The road-roller load is assumed to be equally divided among all of the joists that it can cover, and the wheel loads equally between two joists.

In case that the highway bridge or trestle carries an electric railway, that one of the train loads shown in Fig. 6*f* which most closely approximates to the greatest electric-railway load that will probably be carried by the structure is to be adopted. This live load for each track is to be assumed to occupy ten (10) feet in width of the entire clear roadway of the span to the exclusion of all other live loads on the said ten (10) feet. The equivalent uniformly distributed live loads, given by the curves in Figs. 6*g* to 6*n* inclusive, are to be used when making the computations instead of the concentrations just specified.

The floor system and the secondary truss-members are to be figured for these electric-train loads when passing either the road-roller or the heavy wagon-load; and the trusses as a whole are to be computed for a uniform load found by combining the equivalent electric-railway load, considering it to occupy ten (10) feet of roadway, together with its impact allowance, with the regular uniform live load per square foot of floor on the remaining width of clear roadway, together with its proper impact allowance, provided that the equivalent live load per lineal foot for the cars plus the proper impact allowance exceed the regular live load for a ten (10) foot width of roadway plus its proper impact allowance. If it should not so exceed, the regular uniform live load must be employed.

38. *Impact Loads*

For steam-railway bridges the impact coefficients are to be found by the following formula,

$$I = \frac{165}{nL + 150},$$

where n is the number of tracks and L is the portion of the span length which must be covered by the moving load in order to produce the maximum stress on the piece under consideration. Fig. 7*c* shows curves computed from the above formula for loaded lengths from zero to one thousand feet and for one, two, three, and four tracks.

The corresponding formula for electric-railway bridges is

$$I = \frac{120}{nL + 175},$$

and Fig. 7*d* gives the corresponding curves. (See also p. 131,)

For highway bridges the formula is $I = \frac{100}{nL + 200}$.

In this case n is equal to the total clear width of roadway and foot-

walks in feet divided by twenty (20). Fig. 7e shows the corresponding curves for $n = 1$, $n = 2$, $n = 3$, and $n = 4$. In case that the value of n be fractional the impact can be found by interpolation. There is to be no impact for road-roller loading.

For all movable spans there is to be an impact allowance for dead-load stresses, amounting to twenty-five (25) per cent thereof, to be applied to all parts that could be affected by shock due to starting the span in motion or to bringing it to rest; but, of course, such impact stresses will not combine with the live-load stresses. In swing spans and bascules this dead-load impact must be applied to all truss members and their connecting details; and in vertical lift bridges to the columns of the towers, the suspending ropes, the equalizers, the hangers, and all the connecting details for these parts.

39. *Dead Load*

The dead load for girders and trusses is to include the weight of all the metal, wood, concrete, and other materials in the superstructure, excepting that of those portions resting directly on the abutments, the weights of which do not affect the stresses in the trusses; also any other permanent or temporary load (such as snow) that may be carried by the structure.

The following unit weights are to be assumed in estimating the dead load:

Creosoted lumber, four and one-half (4½) pounds per foot board measure.

Oak and other hard woods, four and a quarter (4¼) pounds per foot board measure.

Yellow pine, three and three-quarters (3¾) pounds per foot board measure.

White pine and other soft woods, two and three-quarters (2¾) pounds per foot board measure.

Rails and their fastenings, seventy (70) pounds per lineal foot per track, unless specially heavy rails be employed, in which case the preceding figure is to be properly increased.

Concrete, from one hundred and forty (140) to one hundred and sixty (160) pounds per cubic foot, according to the character of the stone or gravel used in its manufacture. For reinforced concrete five (5) pounds are to be added to the preceding unit weights.

Asphalt pavement, including binder, one hundred and twenty (120) pounds per cubic foot.

Brick pavement, one hundred and forty (140) pounds per cubic foot.

Steel, four hundred and ninety (490) pounds per cubic foot.

Cast iron, four hundred and fifty (450) pounds per cubic foot.

Earth (used as a covering for masonry or concrete arches), one hundred (100) pounds per cubic foot.

Broken stone for ballasted floors, one hundred (100) pounds per cubic foot.

Snow, compacted, fifty (50) pounds per cubic foot.

Water (carried in pipes) sixty-two and a half (62.5) pounds per cubic foot.

In truss bridges the division of dead load between the upper and the lower chords need be only approximately correct. For ordinary bridges it is sufficiently accurate to assume that two-thirds (2/3) thereof will pertain to the loaded chords.

If in any bridge design the dead load assumed should differ from that computed from the diagram of sections and the detail drawings by an amount exceeding one (1) per cent of the sum of the equivalent live load, impact load, and actual dead load, the calculations of stresses, etc., are to be made over with a new assumed dead load.

40. *Uplift Loads*

There is, or should be, a considerable uplift at the ends of any swing span when it is ready for travel, caused by the end-lifting device. The amount of this uplift per truss or girder is to be assumed as a certain proportion of the entire dead load carried by one arm of the said truss or girder when the span is being swung, which proportion is to be taken from the following table:

TABLE 78*b*

RATIOS OF UPLIFT TO DEAD LOAD FOR SWING SPANS

Spans	Ratios of Uplift to Dead Load	
	Railroad Bridges	Highway Bridges
Up to 150′	1/3	1/4 to 1/6
150′ to 250′	1/4	1/5 to 1/7
250′ to 350′	1/5	1/6 to 1/8
350′ to 450′	1/6	1/7 to 1/9
Over 450′	1/7	1/8 to 1/10

These uplifts are to be adopted both for finding the uplift stresses in trusses and for proportioning the end-lifting machinery; provided, however, that for the latter purpose no assumed uplift per pedestal be less than twenty thousand (20,000) pounds for single-track drawbridges or less than forty thousand (40,000) pounds for double-track drawbridges. For light highway bridges the inferior limit of uplift is to be taken at ten thousand (10,000) pounds at each of the four corners of the span. When uplift stresses tend to increase the section of a member they are to be duly considered, but when they tend to decrease it they are to be ignored.

41. *Wind Loads for Railroad Bridges*

For steam railway bridges the wind loads per lineal foot of span for both the loaded and the unloaded chords are to be taken from the curves given in Fig. 9*b*. The wind loads for the loaded chords include a pressure of three hundred (300) pounds per lineal foot on the train, the centre of which pressure is applied at a height of eight (8) feet above the base of rail. For determining the requisite anchorage for a loaded structure, the train of empty cars shall be assumed to weigh one thousand (1,000) pounds per lineal foot.

In trestle towers the columns and transverse bracing shall be proportioned to resist the following wind-pressures in addition to all other loads:

First. When the structure is loaded, six hundred (600) pounds per lineal foot on stringers and cars, concentrated at a height of one foot above base of rail, and two hundred and fifty (250) pounds for each vertical foot of each entire tower.

Second. When the structure is empty, three hundred and fifty (350) pounds per lineal foot on stringers, assumed to be concentrated one foot above the centre of stringer, and three hundred and fifty (350) pounds for each vertical foot of each entire tower.

The wind loads for longitudinal bracing are to be taken as seven-tenths (0.7) of those for the transverse bracing.

In figuring greatest tension on columns and anchor-bolts, computations are to be made for both the loaded and the unloaded structure, in double-track trestles placing the train of empty cars on the leeward track.

The wind loads of the upper lateral system shall generally be assumed to be carried to the ends of the span by the said lateral system, no part thereof being considered to travel down by the intermediate vertical sway-bracing.

All wind loads are to be treated as *moving loads*. No percentage of impact is to be added to wind loads.

Wind loads for swing spans are specified subsequently in this chapter, as are also those for the design of the machinery of vertical lift and bascule bridges.

In vertical lift bridges the towers are to be figured for a wind load of fifteen (15) pounds per square foot with the movable span in its highest position and for one of thirty (30) pounds per square foot with the said span in its lowest position, the longitudinal wind load on the span being taken as seven-tenths (0.7) of the transverse.

In bascule bridges the structural portions shall be designed for a wind load of thirty (30) pounds per square foot with the span closed, and for one of fifteen (15) pounds per square foot when the said span is in any other position.

42. *Wind Loads for Highway Bridges*

For highway and electric-railway structures the wind loads per lineal foot of span for both the loaded and the unloaded chords are to be taken from the curves shown in Fig. 9*d*. The wind loads for the loaded chords of bridges carrying electric railways include a pressure of two hundred and fifty (250) pounds per lineal foot on the cars, the centre of which pressure is applied at a height of seven (7) feet above the base of rail. These diagrams were figured for a clear roadway of twenty (20) feet. For wider structures, the wind loads for the loaded chords are to be increased two (2) per cent for each foot of width in excess of twenty (20). The wind loads given on the diagram have been computed from detailed designs for simple spans up to seven hundred and fifty (750) feet in length, but beyond this limit they have been assumed; consequently, in designing spans of greater length than this, it will be necessary to check the assumed wind-pressure after the sections are proportioned, using an intensity of twenty-five (25) pounds per square foot. The intensities employed in preparing the curves varied from forty (40) pounds for very short spans to twenty-five (25) pounds for very long ones.

For viaducts carrying highway traffic only, the wind-pressure on the empty structure is to be assumed as three hundred (300) pounds per lineal foot on the spans at the level of the floor, and two hundred and fifty (250) pounds for each vertical foot of each entire tower. The wind loads for longitudinal bracing are to be taken as seven-tenths (0.7) of those for the transverse bracing.

For elevated railroads and for viaducts carrying electric trains, the wind loads are to be taken as eight-tenths (0.8) of those specified for railroad bridges.

All wind loads are to be treated as *moving loads*.

For all highway structures the live load and the wind load shall not be assumed to act together, excepting only that the electric-railway live load must be taken as acting in conjunction with the wind.

Wind loads for swing spans are specified subsequently in this chapter, as are also those for the design of the machinery of vertical lift and bascule bridges.

The wind loads for the design of the towers of vertical lift highway bridges and the structural portions of bascule highway bridges are to be the same as those specified for railway bridges.

43. *Indirect Wind Load or Transferred Load*

For through truss spans with inclined end posts, even with polygonal top chords, the transferred load is to be assumed to produce a tension in the leeward bottom chord that is constant from end to end of span and a similar release of tension on the windward bottom chord. For trusses with parallel chords this assumption is correct, provided that all

the wind-pressure travels directly to ends of span by the horizontal bracing; while for trusses with polygonal top chords the assumption is a compromise, the travel of wind-pressure being ambiguous. The transferred load is to be found by multiplying one-half of the total wind load on the top chord by the vertical distance between the point of contraflexure of the inclined end post and the hip apex and dividing the product by the perpendicular distance between central planes of trusses.

44. *Vibration Load*

In railway bridges the vibration load is a transverse loading, generally in excess of the wind load, applied to the lateral bracing only. The stresses which it produces are not to be added to any other stresses, its sole object being to ensure sufficient sectional areas for lateral members in order to attain proper rigidity for the structure as a whole. For the loaded chords of through and deck spans and for viaduct towers its value is to be taken at seven hundred (700) pounds per lineal foot for single-track structures and eight hundred and fifty (850) pounds per lineal foot for double-track structures. For the unloaded chords the corresponding figures are, respectively, three hundred (300) and three hundred and fifty (350). In computing the stresses caused by vibration loads, they are always to be considered as advancing.

Highway bridges and electric-railway bridges are not to be figured for vibration loadings.

45. *Traction Load*

The total traction load on any portion of a structure is to be taken as a certain percentage of the greatest live load that can be placed on that portion of said structure. For elevated railroads and electric-railway bridges this percentage is to be taken as twenty (20); and for railway bridges it is to be determined by the formula,

$$T = \frac{4000}{140 + L}, \text{ with } T_{max} = 20 \text{ and } T_{min} = 10;$$

where T = percentage,
and L = loaded length in feet.
The values of T may be taken from Fig. 9*e*.

In proportioning the towers and columns of railway trestles and elevated railroads, the said towers and columns between consecutive expansion points are to be assumed to receive no aid from neighboring towers and columns, but must be figured for the greatest possible traction load between the said consecutive expansion points. No percentage of impact is to be added to traction loads. There is to be no traction loading for highway bridges unless they carry electric-railway tracks.

46. *Centrifugal Load*

The centrifugal load is to be computed for the greatest probable velocity of trains by the formula,

$$C = \frac{WV^2}{15R},$$

where C is the centrifugal load per lineal foot, W is the equivalent live load per lineal foot, R is the radius of the curve in feet, and V is given by the formula,

$$V = 60 - 2.5D$$

where D is the degree of curvature. The values of C for curves up to twenty (20) degrees can be taken from Fig. 8*b*.

All portions of the structure affected by the centrifugal load are to be figured to carry properly the stresses induced by the said load in addition to all other stresses to which they may be subjected. It is to be assumed as applied five (5) feet above the base of rail, the average centre of gravity of the moving load. The transferred load on the stringers, girders, or trusses due to the transference of the centrifugal load to the plane of the lateral bracing shall be considered, as well as the stresses produced in the laterals and chords forming the horizontal truss for carrying this load to the ends of the span. The overturning effect of the centrifugal load on the structure as a whole shall also be duly considered. The effect of the shifting of the centre of gravity of the load due to the superelevation of the outer rail shall also be taken into account, as well as the effect of the eccentricity of the load due to the curvature of the track. No percentage of impact is to be added to centrifugal loads. There is to be no centrifugal loading for highway bridges unless they carry electric-railway tracks.

47. *Effects of Changes of Temperature*

In ordinary structures changes of temperature will not affect the stresses in the members, provided, of course, that proper precaution be taken to permit unrestricted expansion and contraction. But in all arches, excepting only those hinged at both ends and at the crown, the stresses caused by the assumed extreme changes of temperature must be computed and duly considered. Temperature stresses must also be given proper consideration in all steel trestles in which the expansion points are placed farther apart than the length of two consecutive bays.

WORKING STRESSES

48. *Intensities of Working Stresses*

The following intensities of working stresses (*i.e.*, pounds per square inch of cross-section) for medium and rivet carbon steels are to be used for all cases, except as hereinafter specified to the contrary.

Tension on gross sections of eye-bars and reinforcing bars, on net sections of all built members, and on net sections of flanges of all beams	16,000 lbs.
Bending on pins	27,000 lbs.
Bearing on pins	22,000 lbs.
Bearing on shop rivets	20,000 lbs.
Bearing on end stiffeners of plate girders (outstanding legs only)	16,000 lbs.
Shear on pins	15,000 lbs.
Shear on shop rivets	10,000 lbs.
Shear on plate-girder webs, gross section	10,000 lbs.
Bearing on expansion rollers, in pounds, where d is the diameter of the roller in inches	600 d.

For field rivets the intensities for bearing and shear are to be reduced twenty (20) per cent.

Turned bolts with driving fit are to be stressed the same as field rivets.

Compression in pounds on struts with fixed ends, $16{,}000 - 60\frac{l}{r}$.

Compression in pounds on struts with hinged ends, $16{,}000 - 80\frac{l}{r}$.

Compression on gross section of flanges of rolled beams 16,000 lbs.

Compression in pounds on gross section of flanges of built beams, $16{,}000 - 200\frac{l}{b}$.

Compression in pounds on forked ends, $10{,}000 - 300\frac{l}{t}$.

In these compression formulæ l is the unsupported length of strut, flange, or jaw-plate in inches, r is the least radius of gyration of the strut in inches, b is the width of the flange in inches, and t is the thickness of jaw-plate in inches.

The intensities of working stresses for nickel steel, established on the basis that the least allowable elastic limit (determined by the drop of the beam) in specimen tests is 55,000 pounds per square inch for plate-and-shape steel and 60,000 pounds per square inch for eye-bar steel, are to be as follows. In case that a still higher grade of nickel steel is procurable, all the intensities, excepting those on rivets, are to be multiplied by the ratio of the higher elastic limit to 55,000 or 60,000, according to the character of the steel under consideration.

Tension on gross sections of eye-bars	28,000 lbs.
Tension on net sections of all built members, and on net sections of flanges of all beams	26,000 lbs.
Bending on pins	45,000 lbs.
Bearing on pins	35,000 lbs.

Bearing on shop rivets	30,000 lbs.
Bearing on end stiffeners of plate-girders	26,000 lbs.
Shear on pins	23,000 lbs.
Shear on shop rivets	14,000 lbs.
Shear on plate-girder webs, gross section	16,000 lbs.
Bearing on expansion rollers, in pounds, where d is the diameter of the roller in inches	900 d.

For field rivets and turned bolts with driving fit the intensities for bearing and shear are to be twenty (20) per cent less than those for shop rivets.

Compression in pounds on struts with fixed ends, $26{,}000 - 110\frac{l}{r}$.

Compression in pounds on struts with hinged ends, $26{,}000 - 150\frac{l}{r}$.

Compression on gross section of flanges of rolled beams 26,000 lbs.

Compression on gross section of flanges of built beams, $26{,}000 - 325\frac{l}{b}$.

Compression in pounds on forked ends, $16{,}000 - 500\frac{l}{t}$.

In these compression formulæ, as before, l is the unsupported length of the strut, flange, or jaw-plate in inches, r is the least radius of gyration of the strut in inches, b is the width of the flange in inches, and t is the thickness of the jaw-plate in inches.

All the preceding figures for both carbon steel and nickel steel are for total equivalent static loads without wind loads added; but when the latter are also included the said figures in the designing of bridges proper are to be increased thirty (30) per cent. Members of lateral systems which are subjected to wind loads alone are to be stressed only as high as truss members for equivalent static loads with wind excluded. As indicated in the clause "Combination of Stresses," certain other combinations of loadings may legitimately stress the metal as high as fifty (50) per cent above the ordinary limits.

The intensities of working stresses for machinery metal are given subsequently in this chapter.

For the various kinds of timber used ordinarily in bridge construction the intensities of working stresses in bending on the extreme fibres, when the proper impact is added to the live load, shall be as follows:

Long-leaf, Southern yellow pine	2,000 lbs.
Douglas fir or Pacific Coast cedar	1,900 lbs.
White oak	1,800 lbs.
Cypress	1,700 lbs.
Short-leaf yellow pine	1,600 lbs.

In all cases the actual and not the nominal dimensions of timbers are to be used when figuring their strength by the preceding intensities.

49. *Bearings upon Masonry*

All bed-plates must be of such dimensions that the greatest pressures on the masonry, including impact, shall not exceed those given in the following table.

Material	Permissible Pressure per Square Inch
Ordinarily good sandstone	200 lbs.
Yellow pine or oak on flat	250 lbs.
Extra good sandstone (not metamorphic)	300 lbs.
Hard brick laid in Portland cement	350 lbs.
Ordinarily good limestone	400 lbs.
Portland cement concrete	500 lbs.
Extra good limestone	550 lbs.
Granitoid	600 lbs.
Metamorphic sandstone of best quality	650 lbs.
Granite	800 lbs.

50. *Compression and Shear in Reinforced Concrete Beams and Slabs*

The greatest intensities of simple compressive stress in reinforced concrete beams and slabs shall not exceed six hundred (600) pounds, except over the supports of continuous beams where an intensity of seven hundred (700) pounds will be permissible.

The greatest intensity of shearing stress in reinforced concrete beams and slabs shall not exceed the following values:

1. For beams and slabs with horizontal bars only and without web reinforcement, 40 pounds.
2. For beams and slabs with at least a half of the longitudinal reinforcement bent up over the supports, 60 pounds.
3. For beams and slabs thoroughly reinforced with web reinforcement, 120 pounds.

In calculating the intensity of shearing stress the depth from the centre of compression to the centre of the steel shall be used.

51. *Reversing Stresses*

In the combination of stresses of opposite kinds, distinction is to be made between the conditions of reversal. If the cause thereof be wind, the effect of reversion is to be ignored. Reversals due to live load combined with impact are to be divided into two classes: first, those which occur in succession during the passage of a live load over the structure, and, second, those which are caused by different loadings. In the first case each of the two kinds of stress is to be increased by seventy-five (75)

per cent of the other, then the section required for each combination is to be computed and the larger of the two results adopted. In the second case the procedure is similar to that just described except that the percentage to be added is fifty (50) instead of seventy-five (75). In either case, though, when figuring the number of rivets for connecting main members, the two opposite stresses are to be added together without reduction, and the sum is to be divided by the permissible stress on one rivet.

52. *Counter System*

Counter systems in all spans must be proportioned to take care of an increase in live load of twenty-five (25) per cent with an increase of unit stress not to exceed twenty-five (25) per cent, additional counter section being employed if required by this increased live load.

53. *Net Section*

The net section of a tension member must be tested along transverse, diagonal, and zigzag lines of rivet holes, taking into account the effect of combined shear and tension on all diagonal sections. The effective area of such diagonal sections can be determined by the use of Fig. 16e. The diameters of the rivet holes shall be assumed as $\frac{1}{8}''$ larger than the diameters of the rivets before driving.

In designing built members care must be taken to see that the value of the section of any component part thereof at any point between adjacent rivets is not taken greater than the value of its net section through the said rivets; and that the difference between the values of the section at any two points is not taken greater than the strength which can be developed by the connecting rivets between the said points.

54. *Effective Bearing Areas*

The effective bearing area of a pin, a bolt, or a rivet shall be its diameter multiplied by the thickness of the piece, except that for countersunk rivets one-half of the depth of the countersink shall be omitted when they are machine driven and the whole thereof when they are hand driven.

55. *Bending Moments and Shears on Pins*

Pins are to be proportioned to resist the greatest bending and shearing stresses produced in them by the bars or struts which they connect. In figuring the bending moments on pins, the stresses shall be assumed as concentrated at centres of bearings.

56. *Combinations of Stresses*

In plate-girder spans and the girders of elevated railroads, the only stresses that need to be considered are those caused by the live, impact, dead, and centrifugal loads. The trusses of both through and deck bridges

will be affected by the live, impact, dead, direct wind, and indirect wind loads; and in some cases also by the centrifugal load. In no case of a properly designed structure will the traction load affect the trusses of bridges to such an extent as to need consideration; consequently the only provision for traction load required in through and deck bridges is adequate, rigid bracing to carry it from the track to the trusses without subjecting any portion of the structure to an improper loading, as, for instance, the flanges of cross-girders to horizontal bending.

In bridges of all kinds, with the exception of arches having less than three (3) hinges, the various loads herein specified shall be combined and the sections of members shall be computed as hereinbefore specified; but in trestles, more especially very high ones, it will be legitimate, when combining the stresses from the various loadings, to reduce some of them or even to ignore some entirely, in order to avoid proportioning for highly improbable or impossible combinations of loads. For instance, when a trestle is situated near the middle of a sharp curve or near the apex of two heavy rising grades, it would be incorrect to assume a high velocity of train. In such cases as these the element of individual judgment in combining the stresses from the various loads and in assuming the sizes of the latter cannot well be eliminated.

Under ordinary conditions the figuring of stresses and sectional areas for the columns of trestles shall be done as follows:

First. Live load, impact, centrifugal load, and dead load, with the usual intensities.

Second. Live load, impact, centrifugal load, dead load, and wind load, traction load, or temperature effect, with an excess of thirty (30) per cent over the usual intensities.

Third. Live load, impact, centrifugal load, dead load, wind load or traction load, and temperature, with an excess of forty (40) per cent over the usual intensities.

Fourth. Live load, impact, centrifugal load, dead load, traction load, and wind load, with an excess of forty (40) per cent over the usual intensities.

Fifth. Live load, impact, centrifugal load, dead load, traction load, wind load, and temperature, with an excess of fifty (50) per cent over the usual intensities.

The preceding adjustment of combinations of stresses and intensities of working stresses shall apply also to arch structures having less than three (3) hinges per arch.

No increase in unit stress shall be allowed for a combination of wind stresses with centrifugal stresses only, or for a combination of traction and centrifugal stresses only; but for combined wind and traction stresses or for combined wind, traction, and centrifugal stresses an increase in unit stresses of thirty (30) per cent will be allowed. These restrictions apply only to the lateral system between the loaded chords.

When combining bending stresses and direct stresses, in the case of chords of riveted truss bridges subjected to transverse loads, there is to be employed the compromise formula,

$$M = \frac{Wl}{10},$$

for finding the bending moment; and the usual intensity must not be exceeded for the combination of extreme fibre stress and the direct compression or tension.

In the case of chords of pin-connected truss bridges, the ends being considered free, the corresponding compromise formula shall be $M = \frac{Wl}{6}$; but if the chords are continuous, the formula to use shall be $M = \frac{Wl}{8}$.

In these two formulæ M is the bending moment in foot-pounds, W is the total load in pounds on the beam, and l is the length of beam in feet between panel-points or supports.

In computing the bending moment due to weight of chord, the formula is to be $M = \frac{Wl}{12}$ for riveted trusses, $M = \frac{Wl}{8}$ for pin-connected trusses with free ends, and $M = \frac{Wl}{10}$ when the chords are continuous.

57. *Bending on Inclined End Posts*

In proportioning inclined end posts of trusses of through-bridges for a combination of all the loads herein specified, together with the bending caused by the wind-pressure which travels transversely down the piece to the pier or abutment, the extreme fibre may be stressed thirty (30) per cent higher than the intensity specified for the direct compression, the bending moment being computed on the assumption that the inclined end post is held in line by the top and the bottom struts of the portal bracing and fixed at the bottom by its connections to the pedestal and the end floor-beam. The position of the point of contraflexure may be taken from Fig. 16*d*.

58. *Bending Due to Weight of Member*

If the extreme fibre-stress resulting from the bending due to the weight only of any member does not exceed ten (10) per cent of the specified intensity of working-stress, the effect of such bending may be ignored; but, if it does so exceed, its effect must be combined with those of the other stresses, using, however, for determining the sectional area, an intensity of working stress ten (10) per cent greater than that specified.

59. *General Limits in Designing Railway Structures*

No metal less than three-eighths ($\frac{3}{8}$) of an inch in thickness shall be used, except for filling-plates.

No channel less than ten (10) inches in depth shall be used except for lateral struts, in which eight (8) inch channels may be employed.

No angles less than $3'' \times 2\frac{1}{2}'' \times \frac{3}{8}''$ shall be used, except for lacing. The length of unsupported outstanding legs of angles in compression shall not exceed twelve (12) times their thickness for main members or sixteen (16) times their thickness for lateral bracing.

No eye-bars less than six (6) inches deep or one inch thick shall be employed; and the depths of eye-bars for chords and main diagonals shall be not less than one fifty-fifth ($\frac{1}{55}$) of the length of the horizontal projection of same.

The shortest span length for trusses with polygonal top chords shall be one hundred and seventy-five (175) feet.

The limit of span length in which the stringers can be riveted continuously from end to end of span shall be two hundred (200) feet. Beyond this limit sliding bearings must be used at one or more intermediate panel points; and in no span shall there be a length of continuously riveted stringers exceeding two hundred (200) feet.

For all compression-members of trusses and for columns of viaducts and elevated railroads the greatest ratio of unsupported length to least radius of gyration shall be one hundred (100), excepting those members the main function of which is to resist tension. In these the limit may be raised to one hundred and twenty (120).

The greatest ratio of unsupported length to least radius of gyration for struts belonging to sway bracing shall be one hundred and twenty (120).

For all horizontal or inclined main or bracing members in tension, the length of the horizontal projection of the unsupported portion of the member shall not exceed one hundred and fifty (150) times the radius of gyration about the horizontal axis.

60. *General Limits in Designing Highway Structures*

The following general limits shall be adhered to in designing highway bridges and viaducts.

The length of any bracket cantilevered beyond a truss or girder shall never exceed seven-tenths ($\frac{7}{10}$) of the perpendicular distance between the central planes of adjacent trusses or girders, unless there be more than two trusses to the span.

No metal less than five-sixteenths ($\frac{5}{16}$) of an inch in thickness shall be used, except for filling-plates; and in important bridges this limit shall be increased to three-eighths ($\frac{3}{8}$) of an inch.

No channel less than six (6) inches in depth shall be used, except for lateral struts, in which five (5) inch channels may be employed.

No angles less than $2\frac{1}{2}'' \times 2\frac{1}{2}'' \times \frac{5}{16}''$ shall be used, except for lacing or railings.

As in railway structures, the length of unsupported outstanding legs of angles in compression shall not exceed twelve (12) times their thickness for main members nor sixteen (16) times their thickness for lateral bracing.

No eye-bars less than four (4) inches deep or three-quarters ($\frac{3}{4}$) of an inch thick shall be employed; and the depths of eye-bars for chords and main diagonals shall be not less than one-sixtieth ($\frac{1}{60}$) of the horizontal length of same.

No adjustable rod shall have less than three-quarters ($\frac{3}{4}$) of a square inch of cross-section.

The shortest span length for trusses with polygonal top chords shall be one hundred and sixty (160) feet.

The limit of span length in which steel stringers can be riveted continuously from end to end of span shall be two hundred (200) feet. Beyond this limit sliding bearings must be used at one or more intermediate panel points; and in no span shall there be a length of continuously riveted stringers exceeding two hundred (200) feet.

For all compression-members of trusses and for columns of viaducts the greatest ratio of unsupported length to least radius of gyration shall be one hundred and twenty (120), excepting those members the main function of which is to resist tension. In these the limit may be raised to one hundred and forty (140). The greatest ratio of unsupported length to least radius of gyration for struts belonging to sway-bracing shall be one hundred and forty (140).

For all horizontal or inclined main or bracing members in tension, the length of the horizontal projection of the unsupported portion of the member shall not exceed two hundred (200) times the radius of gyration about the horizontal axis.

61. *Smoke Protection*

Metal which is subjected to the action of locomotive smoke or other corrosive gases, in addition to being extra well painted, shall have its thickness increased either one-sixteenth ($\frac{1}{16}$) or, preferably, one-eighth ($\frac{1}{8}$) of an inch; otherwise all paint shall be omitted and concrete protection used instead.

62. *General Principles in Designing Structural Metalwork*

In designing all structural metalwork the following principles are invariably to be observed:

All members must be straight between panel points, as curved struts or ties will under no circumstances be allowed, excepting in plate-girder arched ribs.

The axes of all members of trusses or girders and those of lateral systems coming together at any apex of a truss or girder must intersect at a point, whenever such an arrangement is practicable; otherwise the greatest care must be employed to ensure that all the induced stresses and bending moments caused by the eccentricity be properly provided for.

Truss members and portions of truss members must always be arranged in pairs symmetrically about the central plane of the truss, except in the case of single members, the axes of which lie in the said central plane of truss. This applies also to the designing of open-webbed, riveted girders.

In proportioning main members of bridges, symmetry of section about two principal planes at right angles to each other is to be attained wherever practicable; but in designing top chords and inclined end posts this rule cannot generally be followed.

In both tension and compression members, the centre line of applied stress must invariably coincide with the axial right line passing through the centres of gravity of all cross-sections of the members taken at right angles thereto.

The principle of symmetry in designing must be carried even into the riveting; and groups of rivets must be made to balance about centre lines and central planes to as great an extent as is practicable.

In all structural metalwork, excepting only the machinery for operating movable bridges, no torsion on any member shall be permitted, if it can possibly be avoided; otherwise, the greatest care must be taken to provide ample strength and rigidity for every portion of the structure affected by such torsion.

In designing all pin-connected work ample clearance for packing must be provided, and sufficient room must be left for assembling members in confined spaces.

In bridges, trestles, and elevated railroads the thrust from braked trains and the traction must be carried from the stringers or longitudinal girders to the posts or columns without producing any horizontal bending moment on the cross-girders or the lateral diagonals.

In trestles and elevated railroads, the columns must be carried up to the tops of the cross-girders or longitudinal girders, and must be effectively riveted thereto. In no case will it be permitted to cut off the columns and rest the cross-girders or longitudinal girders on top of same.

Every column that acts also as a beam must have a solid web or webs in the direction of the bending, as no reliance shall be placed on lacing to carry a transverse load down the column.

In trestles and elevated railroads every column must be anchored so firmly to its pedestal that failure by overturning or rupture could not occur in the neighborhood of the foot, if the bent were tested to destruction.

The amount of field-riveting must be reduced to a minimum, without, however, diminishing the number of rivets requisite for strength and

rigidity. All designs are to be made so as to facilitate field riveting as much as possible.

Rivets are not to be used in direct tension.

For members of any importance, more than two rivets are to be used for each connection.

In designing short members of open-webbed, riveted work, it is better to increase the sectional area of the piece from ten (10) to twenty-five (25) per cent beyond the theoretical requirement than to try to develop the strength by using supplementary angles at the ends to connect to the plates.

The efficiency of single-angle members in tension shall be taken as sixty (60) per cent, and of two-angle members in tension, as ninety (90) per cent when fastened to the connection plate by rivets passing through the legs which are adjacent to each other, and as seventy (70) per cent when fastened by the legs not adjacent to each other. For compression members the corresponding percentages shall be forty (40), ninety (90), and fifty (50).

Star struts formed of two angles with occasional short pieces of angle or plate for staying the same are not to be used, for better results are obtained by placing the angles in the form of a T.

Compression splices, where only a portion of the section is cut, and where, consequently, perfect abutting of the ends cannot be relied upon, and tension shingle splices shall have a strength ten (10) per cent in excess of that of the section cut; but compression splices, where the whole section is cut and where perfect abutting of ends is a possibility, shall have a strength at least equal to sixty (60) per cent of that of the cut section. The splice must be figured to ensure that it will take care properly of the greatest transverse bending to which it could ever be subjected.

Tension splices in which the entire section is cut at one point shall have a strength equal to that of the cut section.

In all splices and connections the arrangement of rivets and splice metal must be such as to make the splice or connection for each integral part have at least the same proportional strength as the whole.

In all main members having an excess of section above that called for by the greatest combination of stresses, the entire detailing is to be proportioned to correspond with the utmost working capacity of the member, and not merely for the greatest total stress to which it may be subjected. In this connection, though, the reduced capacity of single angles connected by one leg only must not be forgotten.

Designs must invariably be made so that all metalwork after erection shall be accessible to the paint-brush, excepting, of course, those surfaces which are in contact with each other or with the masonry. This requirement rules out all closed columns of every type and description.

The bottom flanges of all girder spans and end floor-beams must clear the masonry by not less than six (6) inches.

In general, details must always be proportioned to resist every direct and indirect stress that may ever come upon them under any probable circumstances, without subjecting any portion of their material to a stress greater than the legitimate corresponding working-stress.

In all designs simplicity in both main members and details is to be considered of the greatest importance.

In all structures rigidity is to be deemed quite as important an element as mere strength.

Structures on skews are to be avoided whenever it is practicable to do so.

The use of more than a single system of cancellation in bridges shall be confined entirely to lateral systems and sway-bracing, except that at mid-panels of trusses two rigid diagonals connected at their intersection may, for appearance, be employed, provided that either diagonal shall have sufficient strength to carry the entire shear in tension, and that the adjacent vertical posts be figured accordingly.

The use of redundant members in structures shall not be allowed, excepting only in the case just mentioned of rigid mid-panel diagonals.

In all designing true economy must be given the utmost consideration, and no useless material must be employed, every pound of metal in the structure having a legitimate function; but economy of material must not be quoted as an excuse for using inferior details or scamping the work in respect to strength, rigidity, or appearance.

In all structural work the subject of æsthetics must be duly considered; and all designs are to be made in harmony with the principles thereof, to as great an extent as the money available for the work will permit or as the environment of the structure calls for.

63. *Riveting*

In railway bridges the rivets used shall generally be seven-eighths (⅞) inch in diameter, smaller ones being employed for small channel flanges and legs of angle-irons less than three (3) inches wide. In heavy work the rivet diameter should be increased to one inch, and in very heavy work to one and an eighth (1⅛) or even one and a quarter (1¼) inches. In highway bridges for ordinary work the rivet diameters may be made three-quarters (¾) of an inch.

For very long grips tapered rivets are to be employed.

The proper diameters for rivets in flanges of channels are as follows:

Depth of channel.....	6″	7″	8″	9″	10″	12″	15″
Diameter of rivet.....	⅝″	⅝″	¾″	¾″	¾″	¾″	⅞″

The pitch of rivets in all classes of work in the direction of the stress shall never exceed six (6) inches, or sixteen (16) times the thickness of the thinnest outside plate, nor ever be less than three (3) diameters of

the rivet—preferably about three and a half (3.5) diameters. At the ends of compression members it shall not exceed four (4) times the diameter of the rivets for a length equal to twice the width of the member, but in no case shall less rivets be used than the theory calls for. In members composed of two angles, however, a pitch of twelve (12) inches will be allowed for riveting the said two angles together.

When two or more thicknesses of plate are riveted together in compression members, the outer row of rivets shall not be more than four (4) diameters from the side edge of the plate.

In flanges of plate-girders and chords, carrying the floor, the pitch shall not exceed four (4) inches.

No rivet-hole centre shall be less than one and a half ($1\frac{1}{2}$) diameters from the edge of a plate, and, whenever practicable, this distance is to be increased to two (2) diameters.

The rivets when driven must completely fill the holes.

The rivet-heads must, in general, be round; and they must be of uniform size for the same-sized rivets throughout the work. They must be neatly made and concentric with the rivet-holes, and must thoroughly pinch the connected pieces together.

Rivets with flat heads shall be preferred to countersunk rivets; the height or thickness of the flat head shall be three-eighths ($\frac{3}{8}$) of an inch.

In important members rivets shall not be countersunk in plates of thickness less than one-half of the diameter of the rivet. Rivets with flattened heads shall be assumed to have only eight-tenths (0.8) of the strength of rivets that have full heads.

Flanges of stringers and girders carrying the vertical load from the ties shall have enough rivets to transmit properly both the horizontal and the vertical shears from flange to web.

Rivets carrying calculated stress and having a grip exceeding four (4) diameters shall be increased in number at least one per cent for each additional sixteenth inch of grip.

Wherever possible, all shop rivets shall be machine-driven, and the machines must be capable of retaining the applied pressure until after the upsetting is completed.

Field-riveting must be done with a button sett; the heads of the rivets must be hemispherical, and no rough edges must be left.

Wherever possible, all field rivets shall be driven by pneumatic power.

All rivets in splice or tension joints are to be arranged symmetrically so that each half of any tension member or splice-plate shall have the same uncut area on each side of its centre line.

No rivet is to have a less diameter than the thickness of the thickest plate through which it passes, unless the holes be drilled.

The effective diameter of any rivet shall be assumed the same as its

diameter before driving; but, in making deductions for rivet-holes in tension-members, the diameter of the holes shall be assumed one-eighth ($\frac{1}{8}$) of an inch larger than that of the rivet. In the effective area of riveted members, pin, bolt, and rivet holes shall be counted out for tension, and bolt and pin holes shall be counted out for compression.

64. *Details of Design for Rolled I-Beam Railway Spans*

Rolled I-beams used as longitudinal girders shall have, preferably, a depth not less than one-twelfth ($\frac{1}{12}$) of the span. They shall be proportioned by their moments of inertia. The unsupported length of the top flange shall not exceed twelve (12) times its width. Either one or two beams per rail will generally be used. In the former case the spacing should be six (6) feet six (6) inches, and in the latter case the two beams carrying a rail should be spaced symmetrically about the centre line of said rail, preferably with a distance of two (2) feet six (6) inches between contiguous girders. Three beams per rail may be used where a very long span or a very shallow floor is necessary; and in this case one of the beams should be placed directly under the rail, and the other two spaced symmetrically about the centre line of said rail, and preferably one (1) foot three (3) inches from it. Where a concrete slab encasing the beams solidly is employed, no bracing of any kind is necessary. In case a concrete slab rests on top of the beams and grips their top flanges effectively, the only bracing required will be a frame at each end; and this may be omitted if the ends of the beams are encased solidly in the abutments. Where a timber deck is adopted, there shall be a bracing frame at each end, and the top flanges shall be stayed by diagonal bracing of angles, riveted to the webs of the beams as near to the top flange as is practicable. Where more than two beams per track are employed, the bracing should be placed between the two inner beams only, and solid web diaphragms should be placed between the beams carrying each rail at each panel-point of the bracing. Each I-beam is to have at each end a pair of stiffening angles, and two additional ones in case the end shear require it. These angles are to fit tightly at both top and bottom against the flanges. Under each end of each I-beam there is to be riveted a bearing plate of proper area and thickness (never less than three-quarters [$\frac{3}{4}$] of an inch) to distribute the load uniformly over the masonry, the said plate to be continuous under all the beams that support each rail; and it is to be bolted to the masonry with two fox bolts per beam, one and one-quarter ($1\frac{1}{4}$) inches in diameter, and extending one (1) foot into the masonry. Where the ends of the beams are encased solidly in the concrete of the abutments, the bearing plate may be omitted; and in this case the end stiffeners are unnecessary provided that the flanges alone are able to distribute the load properly over the masonry. The end stiffeners may also be omitted in case a concrete slab encasing the beams solidly be used.

65. *Details of Design for Rolled I-Beam Highway Spans*

Rolled I-beams used as longitudinal girders shall have, preferably, a depth not less than one-fifteenth ($\frac{1}{15}$) of the span. They shall be proportioned by their moments of inertia. The spacing shall generally not exceed three (3) feet six (6) inches for wooden floors or five (5) feet for a reinforced concrete base. The specifications for railway spans will govern in general; but except in the case of a structure carrying electric-railway tracks on an open timber deck, the floor should be so designed as to stiffen the top flanges of the beams effectively, and all diagonal bracing should be omitted. The bearing plate at each end of each beam may be as thin as five-eighths ($\frac{5}{8}$) inch, and generally there will be a separate plate for each beam. Two fox bolts per beam shall be used, each one and one-quarter ($1\frac{1}{4}$) inches in diameter and extending one (1) foot into the masonry.

66. *Details of Design for Plate-Girder Railway Spans*

Plate-girders shall have, preferably, a depth not less than one-tenth ($\frac{1}{10}$) of the span. All plate-girders, whenever it is practicable, shall be built without splices in the web; and when such become necessary, the smallest possible number of them shall be adopted. The splice-plates and rivets for the splices shall be such as to develop in every respect the full strength of the net section of the web, the main splice-plates extending from flange to flange and having generally three (3) rows of rivets on each side of the joint, and being figured to take care of the bending strength of the portion of the web they cover, and also the shearing strength of the entire web. The bending strength of the portion of the web covered by the flanges shall be cared for either by splice-plates covering the vertical legs of the flange angles, or else by the excess section of the flange at that point. There must be sufficient rivets through the flanges to develop the bending strength in a distance not greater than two (2) feet, the stresses on the said rivets due to the increment of flange stress being duly considered.

Splices in flange-plates and angles must always be avoided when sufficiently long plates and angles are procurable. Where flange-splices are unavoidable, they must be so located that no two pieces of either the flange or the web shall be spliced within two (2) feet of each other, and so that no flange-splice shall occur at any point where there is not an excess of sectional area above the theoretical requirements. Every non-continuous flange-piece shall be fully spliced so that the splicing plates and rivets shall have a calculated strength at least ten (10) per cent greater than that of the section spliced. Field-splicing of plate-girders will never be allowed for fixed spans, except in structures for foreign countries.

At least forty (40) per cent, and preferably one-half, of every flange section must consist of angles or of angles and side-plates; but side-

plates should be avoided whenever possible. The number of cover-plates must be made as small as practicable, in no case exceeding three (3) per flange. The lengths of these cover-plates must be such as to make them project at each end not less than eighteen (18) inches beyond the point determined by the calculations for the requisite resistance to bending.

Where two or three cover-plates per flange are used, they shall be of equal thickness, or shall decrease in thickness outward from the angles. The cover-plates shall not extend more than four (4) inches or eight (8) times the thickness of the outer plate beyond the outer line of rivets. With cover-plates more than fourteen (14) inches wide, four (4) lines of rivets shall be used.

The compression-flanges of plate-girders shall generally be made of the same gross section as the tension-flanges; and they shall, preferably, be so stiffened laterally that this section will be sufficient. The unsupported length of the compression flange shall not exceed twelve (12) times its width for deck girders on tangent and for through girders; but for deck structures on curves the said unsupported length shall not exceed six (6) times the said width. For deck girders supporting ties on the top flanges it is generally best to avoid the use of cover-plates. Where two angles fail to provide sufficient section, the flange should be composed of four angles with the edges of the vertical legs in contact and having side-plates placed on these vertical legs when required.

In deck-spans there are to be bracing frames at the ends, and in spans of thirty (30) feet and over also at intermediate points not more than fifteen (15) feet apart; and there is to be an effective system of diagonal bracing of angles between the top flanges of the contiguous girders for each track. For deck spans of seventy (70) feet and over there is to be a similar system of diagonal bracing between the bottom flanges.

For double-track deck-spans over sixty-five (65) feet long, a system of top lateral bracing shall be used between the two inner girders, as well as between each pair of girders under each track. Intermediate bracing frames shall not be used between the girders of adjacent tracks.

In half-through spans the girders are to be divided into panels not exceeding in length twelve (12) times the width of the flange, and there is to be a bracket of web plate and angles at each end of each cross-girder extending to the top flange of the longitudinal girder, so as to stay the latter effectively. This bracket must extend inward to the standard clearance lines. It will not be permissible to dispense with the steel stringers by resting the ties on the bottom flanges or upon special shelf angles. Half through plate-girder spans are generally to have a rigid, double-cancellation lower-lateral-system of angles riveted together by plates and angles at their intersections and to the bottom flanges of the steel stringers, if the latter be employed; but if a steel trough floor be used, the laterals are to be omitted. In this last case brackets similar to those above specified and similarly spaced shall be riveted to the troughs.

When steel stringers are used, their top flanges shall be braced laterally at points spaced not to exceed twelve (12) times the width of the said flanges.

The thickness of any web plate shall not be less than one-two hundredth ($^1/_{200}$) of the unsupported distance between flange angles, but not more than one-half ($\frac{1}{2}$) inch unless a greater thickness be required for shear.

Web-stiffeners shall be placed at the ends of plate-girder spans, also at all points of concentrated loading and at intermediate points at distances not exceeding either the depth of the girder or five (5) feet, except in the case of shallow girders where the shear, including impact, does not exceed five thousand (5,000) pounds per square inch of web section. Under such circumstances the spacing of intermediate stiffeners may be made as great as three (3) feet six (6) inches. All stiffeners must bear tightly at top and bottom against the flange angles. Under end stiffeners there must be fillers flush with the flange angles, but intermediate stiffeners shall, preferably, be crimped. All stiffeners must be in pairs. End stiffening angles shall extend as nearly as practicable to the outer edges of the flange angles. They must have sufficient area in the outstanding legs only to carry the entire end shear, including impact, with the specified intensity of working-stress, no reliance being placed on the fillers. The latter shall have the same thickness as the flange angles. The sections of intermediate stiffening angles shall not be less than those given in the following table:

TABLE 78c

INTERMEDIATE STIFFENERS FOR GIRDERS

Outstanding Leg of Flange Angle	Dimensions of Angles
8″—for girders over nine (9) feet in depth	6″ × 3½″ × ⅜″
8″—for girders up to nine (9) feet in depth	5″ × 3½″ × ⅜″
6″	4″ × 3″ × ⅜″
5″	3½″ × 3″ × ⅜″
4″ and under	3″ × 3″ × ⅜″

In proportioning the flanges of plate girders, one-eighth (⅛) of the gross area of the web is to be assumed as concentrated at the centre of gravity of each flange; or, in other words, after having found the net sectional area required for the tension-flange by ignoring the resistance of the web to bending, there is to be subtracted therefrom one-eighth (⅛) of the gross area of the web-plate.

At the ends of all plate girders there must be sufficient rivets in each flange to transfer properly thereto from the web the resultant of the total end shear and the vertical load thereon in a distance equal to the effective depth of the girder.

At the ends of cover-plates the spacing of the rivets which attach the covers, for a length equal to at least twice the width thereof, shall not exceed three (3) inches.

For spans less than fifty (50) feet in length, there is to be placed under each end of each plate girder a steel casting at least six (6) inches high, which shall be figured so as effectively to distribute the load uniformly over the masonry. A sole plate three-quarters (¾) of an inch thick shall be riveted to the bottom flange of the girder, and shall bear directly on the said casting, the bottom surface of the sole plate and the top surface of the casting being planed longitudinally. The girder shall be bolted to the casting with due provision for expansion and contraction, and the casting is to be bolted to the masonry with two (2) fox bolts, one and one-quarter (1¼) inches in diameter, extending eighteen (18) inches thereinto. Girders fifty (50) feet long and over are to have rocker-ends and rollers. These shoes shall be so designed as to prevent any transverse motion or possible uplifting. The minimum allowable diameter of rollers shall be six (6) inches, and they must be enclosed in dust tight boxes. Each shoe must be bolted to the masonry by four (4) fox bolts, one and one-quarter (1¼) inches in diameter, extending eighteen (18) inches thereinto.

Bridges on an inclined grade without pin shoes shall have the sole plates beveled so as to make the sliding surface horizontal.

67. *Details of Design for Highway, Plate-Girder Spans Without Steel Floor Systems*

In designing a span of this type, the specifications for railway plate-girder spans are to be followed in general. The depths of the girders shall, preferably, be not less than one-twelfth ($^1/_{12}$) of their span. The use of metal five-sixteenths ($^5/_{16}$) inch thick will generally be permissible, and for light girders intermediate stiffening angles as small as two and a half (2½) by two and a half (2½) inches may be used. For light, cheap structures the diagonals of the lateral systems and sway frames may be made of adjustable rods. The minimum diameter of rollers in expansion shoes shall be four (4) inches. For light structures rocker-ends and rollers will be required only in spans exceeding seventy (70) feet in length.

68. *Details of Design for Highway, Plate-Girder Spans with Steel Floor Systems*

In structures of this type there will generally be two lines of longitudinal girders placed at about the quarter-points of the cross-section, the central portion of the roadway being supported by cross-girders between the main girders, while the outer portions are carried on cantilever brackets placed at each end of each cross-girder.

The stringers should, preferably, be rolled I-beams or channels, the former being generally used for intermediate stringers, and the latter for the stringers at the sides of the structure. They shall be proportioned by their moments of inertia. Their length shall, preferably, not exceed

fifteen (15) times their depth. The flooring should be so designed as to stiffen their top flanges effectively, if possible, otherwise the said flanges must be supported laterally at points spaced not to exceed twelve (12) times their width. They shall generally be riveted to the webs of the cross-girders or cantilevers; but if they be set on the top flanges (which will rarely be necessary except for sidewalk stringers), they must be braced transversely by bracket plates riveted to the cross-girders or to the cantilever beams. The end stiffeners are to be faced or otherwise treated so as to ensure that the stringers will be of exact length, and that they will have a uniform bearing against the webs of the cross-girders or cantilever brackets.

The cross-girders and cantilever beams shall preferably be plate-girders. In general, they will be designed in accordance with the specifications previously given for the girders of railroad plate-girder-spans. The minimum thickness of metal is to be five-sixteenths ($^5/_{16}$) of an inch, and the minimum size of angle used for intermediate stiffeners, two and a half ($2\frac{1}{2}$) by two and a half ($2\frac{1}{2}$) inches. Due consideration shall be given to the effects on the floor-beam of live loads on the cantilever arms; and in figuring the rivet pitches in the flanges of the cantilever beams, due account shall be taken of the effect of the inclination of the bottom flange. The effect of vertical loads on the top flanges of floor-beams and cantilever beams must be considered when figuring rivet pitches. The end stiffeners are to be faced or otherwise treated so as to ensure that they will have a uniform bearing against the webs of the main girders; and the bottom flanges of the cantilever brackets are to be faced so as to have a full bearing on the said webs. The bottom flanges of the cross-girders must be similarly faced when, as is usual, the cantilever brackets are of the same depth as the cross-girder. When the cantilever is shallower, two horizontal angles milled to bear on the end stiffener angles of the cross-girder shall be placed on the cross-girder web opposite the bottom flange of the cantilever. These angles shall have sufficient area in their outstanding legs to carry the entire thrust from the said bottom flange of the cantilever, and shall be connected to the web of the cross-girder by a sufficient number of rivets to transfer thereto the said thrust. These angles shall not be crimped, but shall have fillers under them as required. The entire tension from the top flange of the cantilever shall be provided for by a strap plate riveted to the top flange of the cross-girder and cantilever, which shall preferably be at the same elevation; and generally the top of the upper flange of the main girder is to be at this same elevation.

The top flanges of the cross-girders are to be stayed at points spaced not to exceed twelve (12) times their widths, and preferably spaced so that the gross section of the tension flange will suffice for the compression flange. These supports will generally be furnished by the stringers, or by the flooring directly. The bottom flange may also have to be

stayed, when there is considerable stress reversal with live loads on the cantilevers only. The bottom flange of the cantilever is to be so stayed that the unsupported length shall not exceed twelve (12) times its width. This support is usually to be furnished by a stringer, a bracket plate on the end of the stringer being riveted to a full-depth stiffener angle on the cantilever in case the stringer does not extend down to the bottom flange. When a concrete floor slab is used, this will stay the stringers longitudinally; otherwise diagonal bracing between the outside lines of stringers and the main girders must be adopted in one panel per span.

The lateral system is usually to consist of a double-cancellation system of rigid diagonals at the elevation of the bottom of the floor-beams. These diagonals are generally to be composed of two angles riveted back to back. No provision for traction forces will be necessary, unless the structure carry electric railway tracks on an open timber deck. In this case one horizontal truss per span is to be formed at the elevation of the bottom of the stringers carrying the electric railway, to transfer the traction loads to the main girders. The laterals should be utilized for a portion of this truss, in case they are close to the bottom of the stringers.

Under each end of each end floor-beam there is to be provided a solid-web bracket riveted to the bottom flange of the floor-beam and to the end stiffeners or web of the main girder, in order to transfer the transverse loads down to the shoes. Should there be no end floor-beam at one end of a girder, an open-web bracing frame should be riveted to the end stiffeners, extending up as high as the stringers will permit. In long spans there should be used, at each end of each intermediate floor-beam, a diagonal brace of one or two angles extending from the bottom of said floor-beam down to the bottom flange.

The design of the main girders shall in general conform to the specifications for the girders of railroad plate-girder spans. Metal as thin as five-sixteenths ($^5/_{16}$) inch may be used. The length should preferably not exceed twelve (12) times the depth. The top flange should be so stayed that the unsupported length will not exceed twelve (12) times its width, and, preferably, so that the gross area of the bottom flange will suffice for that of the upper flange. In case a concrete floor-slab is used, it should rest on the top flange, so as to stay it effectively; but with a timber deck no reliance can be placed on the stiffness of the floor, and the top flange shall be assumed to be stayed only by the cross-girders, unless special diagonal bracing of angles be employed to stiffen it at the centre of each panel.

The details of the shoes must conform to the specifications for railroad plate-girder spans, except that for light structures the diameter of the rollers may be as small as four (4) inches, and that rocker-ends and rollers are to be used only for spans exceeding seventy (70) feet in length.

69. *Provision against Excessive Deflection*

If local conditions make necessary a depth of plate girder less than one-twelfth ($^1/_{12}$) of the span for railway bridges, or less than one-fifteenth ($^1/_{15}$) of the span for highway bridges, enough metal shall be added to the web and flanges to reduce the deflection to that which would occur with the above limiting depths. A similar provision is to be made for rolled I-beam spans when the depths are less, respectively, than one fifteenth ($^1/_{15}$) and one-eighteenth ($^1/_{18}$) of the span.

70. *Details of Design for Open-Webbed, Riveted-Girder Spans*

All open-webbed, riveted girders shall be riveted up completely in the shop whenever possible, as field-riveting will usually be allowed only for the lateral bracing, except in structures for foreign countries. Whenever, for any reason, this method is impracticable, all of the truss-members will have to be assembled in the shop, after which the rivet-holes for the connections shall be reamed so as to ensure perfect fitting in the field. The use of shallow, open-webbed, riveted girders shall be avoided whenever possible, for the reason that they are quite as expensive and never as satisfactory as plate girders. In case, though, of their being required, as for instance in elevated railroads occupying city streets, they are to be provided with short, substantial web-plates at the ends and at all intermediate points where connections are made to other girders. In no case will it be permissible to use flats instead of angles for web-members, but tees may be employed, provided their heads be wide enough to permit of satisfactory riveted connections.

At all intersections of web-members with chords, connecting or gusset plates are to be used; for it is not permissible to attach web angles directly to chord angles without using an intermediary plate. The thickness of gusset plates shall be proportionate to the stresses to be transferred, and their resistance both to shearing out through the lines of rivets and to the direct and the bending stresses induced by the members connected to them shall invariably be ample. The exact intersection at a point of all the gravity lines of girder-members assembling at any apex must be adhered to in the designing of open-webbed, riveted girders.

In designing all riveted connections, the greatest care is to be taken to make connecting plates and groups of rivets balance about centre lines of stress, especially where passing from riveted work to pin-connected, as in the case of a riveted span with hinged ends at pedestals.

In all other particulars, the designing of open-webbed, riveted work is to comply, wherever practicable and proper, with the specifications for plate-girder and riveted-truss spans.

71. *Details of Design for Riveted-Truss Railway Spans*

The sections of the top chords and those of the inclined end posts of through-spans shall consist, generally, of two built channels and a cover-plate, each channel being formed of a web and two angles, the upper one small and the lower one much larger, so as to bring the centre of gravity of the entire box section of the member as close as possible to the mid-plane of the web-plates. In no case will more than one cover-plate be allowed, and this is to be made as thin as is proper.

Main vertical posts shall, generally, be composed of two laced channels, preferably rolled ones, although built ones must be used where large sections are required. Secondary vertical posts may be built of two rolled channels laced, or of four angles in the form of an I with either a single line of lacing or a web. The channels of vertical posts should usually have their flanges turned inward.

Main diagonals shall generally be composed of two rolled or built channels, except for the intersecting diagonals in the centre panel of a truss with an odd number of panels, which should usually be composed of four angles in the form of an I. Secondary diagonals may be made of either two channels—generally rolled—or four angles in the form of an I. All diagonals which have to sustain compression must be laced, but for others the use of batten plates about three (3) feet from centre to centre will be satisfactory. The channels of diagonals will ordinarily have their flanges turned inward.

Hangers will generally be composed of four angles in the form of an I, with a central web or a single line of batten plates. For heavy sections, the use of two rolled or built channels, with two lines of batten plates, may be necessary. These channels will generally have their flanges turned inward.

The bottom chords in short span bridges will usually be composed of four angles in the form of an I, with a single line of lacing in the end panels, and batten plates in the central panels. The use of a central web is not often advisable; and when employed, drain-holes about two (2) inches in diameter should be used, spaced about three (3) feet from centre to centre. For longer spans the bottom chords shall generally be made of two built channels having the flanges turned inward, with two lines of lacing in the end panels, and two lines of batten plates in the central panels.

Upper lateral struts, overhead transverse struts, and web-stiffening struts shall, preferably, be made of four angles with one line of lacing. In case, however, the said angles be spaced very far apart, as in lateral struts connecting unusually deep top chords, they are to be placed on the corners of a rectangle, with their legs inward, and laced on all four faces of the box strut thus formed.

In short spans, two angles riveted back to back, or even a single large

angle, may be used for lower lateral diagonals; but for long spans the said diagonals are preferably to be made of four angles in the form of an I with a single line of lacing. When two angles are used, a single plate must not be depended on to form the splice at the intersection of the diagonals, but there must be employed also a top splice plate attached to hitch angles which rivet in the field to the vertical legs of the diagonal angles.

Diagonals for upper lateral systems and vertical sway-bracing shall, preferably, be built of four angles in the form of an I with a single line of lacing; but, for structures where this section would involve an extravagant use of metal, two of the angles, one at top and one at bottom, may be omitted, thus making each strut consist of two angles laced, provided, of course, that where the struts cross they shall be rigidly connected by two plates of ample size. This unbalanced section for such diagonals is to be avoided whenever it can be done without undue use of metal. In no case, though, will it be permissible to use angles in tension that are not capable of properly resisting compressive stress, with due regard for the specified limit of ratio of unsupported length to least radius of gyration.

In designing transverse lateral and overhead struts and their connections it must be remembered that their main function is to hold rigidly the chords or posts to place and line, and not merely to resist as columns the greatest calculated direct stresses to which they may be subjected. For this reason such struts must have ample section for rigidity, and the connecting plates at their ends must grip both connected members effectively.

Stringers for truss-bridges shall almost invariably be built of plates and angles, and no cover-plates will be allowed for the flanges. Their depths shall be made not less than the most economic ones in respect to weight of metal required, provided that the bridge clearance will permit, and never less than one-twelfth ($^1/_{12}$) of the span. No splice will be allowed in their flanges nor any in their webs, provided that sufficiently long web-plates are procurable. The compression-flanges shall be made of the same gross section as the tension-flanges; and they shall be so stiffened that this section shall be ample to care for the compression stress, and under no circumstances shall the unsupported length exceed twelve (12) times the width of flange. Rigid diagonal bracing of angles is invariably to be used between the top flanges of stringers, and rigid bracing-frames are to be employed at all expansion points. If the panel length exceed thirty (30) feet, there shall be a bracing-frame at mid-length between the stringers pertaining to each track, but not between those of adjacent tracks. In respect to intermediate stiffening angles for stringers, the rules governing those for plate-girder spans are to be followed; but the end stiffeners are to be faced or otherwise treated so as to make the stringers of exact length throughout, and so as to effect a uniform bear-

ing of the end stiffeners against the webs of the cross-girders. In through spans the outstanding legs of the end stiffening angles of the stringers are to be made six (6) or seven (7) inches wide with the rivets placed as near the tips of said legs as is proper.

In respect to proportioning of flanges and number of rivets required, the rules given for plate-girder spans are to apply also to stringers. The said rules are to apply also to cross-girders, as shall also those relating to stiffeners, splices, cover-plates, and size of compression-flanges that are given for plate-girder spans. Wherever it is necessary to notch out the corners of the cross-girders to clear the chords or the end pins, the greatest care must be taken to provide an adequate means for transferring the shear to the posts without impairing either the strength or the rigidity. If necessary, in through-bridges the web of the cross-girder can be divided into three parts so as to let the end portions project above the top flange and form brackets that will afford opportunity for using an ample number of rivets to connect to the posts, and that will strengthen properly the otherwise weakened cross-girder.

In order to carry the thrust of trains from the stringers to the trusses through the lower lateral diagonals, the latter and the stringers are to be made to form complete horizontal trusses by running angles between stringers at the level of the bottom flanges. In single-track bridges two pieces of angle per panel running transversely between stringers at the intersection of the latter with the diagonals will suffice; but in double-track bridges there will be required one such angle per panel between inner stringers, two diagonal angles per panel to run from where the lateral diagonals intersect the outer stringers to where the inner stringers meet the cross-girders, and either one or two diagonal angles per panel running from where one inner stringer meets the cross-girder to where the other inner stringer meets the lateral diagonal. In other words, only one-half of each panel is to be provided with traction bracing.

All plates, angles, and channels used in built members of trusses must, if practicable, be ordered the full length of the piece; otherwise, the partial splices must develop one and one-tenth ($1\frac{1}{10}$) times the full strength of the portion cut, without any reliance being placed on abutting ends for carrying compression.

In total splices at the ends of compression members, where the entire section is cut at one point and the ends are faced, the detailing must be proportioned for at least sixty (60) per cent of the capacity of the member; and in similar total splices at the ends of tension members, for one hundred (100) per cent of the said capacity. In total shingle splices in either tension or compression members, the detailing must be proportioned for at least one hundred and ten (110) per cent of the total strength of the member.

The unsupported widths of plates stressed in compression, measuring between centre lines of rivets, shall not exceed thirty-two (32) times

their thickness, except in the case of cover-plates for top chords and inclined end posts, where the limit may be increased to forty (40) times the thickness. Where webs are built of two or more thicknesses of plate, the rivets that are used solely for making the several thicknesses act as one plate shall in no case be spaced more than twelve (12) inches from each other or from other rivets connecting the said component thicknesses together. The least allowable thickness for such compound web-plates shall be seven-eighths (7/8) of an inch.

The open sides of all compression members composed of two rolled or built channels, with or without a cover-plate, shall be stayed by tie-plates at ends and by diagonal lacing-bars or lacing-angles at intermediate points; and compression members composed of four (4) angles in the form of an I or of two (2) angles in the form of a channel shall be similarly stayed. In any rigid tension member or in a compression member that has a central web connecting the opposite halves of the piece, the lacing may be omitted and replaced by tie-plates.

The end tie-plates shall be placed as close as practicable to the ends of the compression members. For main members of trusses their thickness shall not be less than one-fiftieth (1/50) of the distance between the centre lines of the rivets by which they are connected to the flanges, unless the said tie-plates be well stiffened by angles, in which case they may be made as thin as three-eighths (3/8) of an inch; and their lengths shall never be less than their widths, unless they be close to a web diaphragm of the member, in which case they may be as short as twelve (12) inches. For members of the lateral and sway bracing, the thickness of the end tie-plates shall never be less than one-sixtieth (1/60) of the distance between the centre lines of the rivets by which they are connected to the flanges, and their lengths shall never be less than eight-tenths (8/10) of their widths. In case the use of intermediate tie or batten plates is permissible, their thickness shall be the same as that specified for the corresponding end tie-plates, and their lengths may be as small as one-half of that specified for the said end tie-plates, but never less than nine (9) inches.

The lacing of compression members must be strong enough to resist, in addition to actual transverse loads, the shear given by the formula,

$$S = \frac{200\,P}{16{,}000 - 60\,\dfrac{l}{r}};$$

where S = shear on the lacing,
P = total compression on the member,
l = unsupported length of member,
and r = radius of gyration of member,
l and r being taken in a direction parallel to that of the lacing.

Lacing may be either single or double, the former generally being pref-

erable. The bars or angles in single lacing shall usually make angles of about sixty (60) degrees, and those in double lacing about forty-five (45) degrees with the axis of the member; but for light, unimportant struts these values may be decreased somewhat. In order to provide ample room for painting, the bars shall be so arranged, and the spacing of the leaves of the member shall be such, as to permit of the insertion of a cylinder four (4) inches in diameter at any point in the system. Lacing bars may be connected to the flanges by only one rivet at each end, unless the shear above specified shall require a greater number; but lacing-angles must always be connected by at least two (2) rivets in each end. The axes of adjacent lacing-bars or angles shall preferably intersect on the line of rivets in the flanges of the main member by which they are connected thereto. The bars or angles in double lacing must be riveted at their intersection.

For main members of trusses the thickness of lacing-bars shall never be less than one-fortieth ($1/40$) of the distance between end rivets for single lacing and one-sixtieth ($1/60$) thereof for double lacing, measuring between inmost rivets in case there be more than one rivet in each end. For members of lateral and sway-bracing, the corresponding limits shall be one-fiftieth ($1/50$) and one-seventy-fifth ($1/75$). The minimum width of bar in which a seven-eighths ($7/8$) inch rivet may be used is to be two and one-half ($2\frac{1}{2}$) inches, and the minimum width of angle leg, three (3) inches. For three-quarter ($3/4$) inch rivets the corresponding limits are to be two and one-quarter ($2\frac{1}{4}$) inches and two and one-half ($2\frac{1}{2}$) inches. The smallest section for a lacing-bar shall be two and one-quarter ($2\frac{1}{4}$) inches by three-eighths ($3/8$) of an inch, and the smallest section for a lacing-angle, two and one half ($2\frac{1}{2}$) inches by two (2) inches by three-eighths ($3/8$) of an inch.

Pins are to be proportioned to resist the greatest shearing and bending produced in them by the members which they connect.

In detailing members composed of four angles in the form of an I with a single line of lacing or tie-plates, the clear distance between backs of angles shall never be made less than three-quarters ($3/4$) of an inch, in order to permit the insertion of a small paint brush.

The least allowable diameter for expansion rollers is six (6) inches; and they must be made segmental. They are to be supported directly on a cast-steel pedestal, and the detailing must be so designed as to permit of a free movement of the rollers in the longitudinal direction of span sufficient to take up the extreme variations in length due to temperature changes and live-load chord stresses, and at the same time prevent any transverse motion of the end of the span. The rollers are to be covered by an apron which makes the enclosed space practically dust-tight; and the said apron is to be removable so as to permit of the cleaning of the said enclosed space. The boxing, however, must not retain water. Segmental rollers shall be geared to the upper and the lower plates.

All shoe-plates, bed-plates, and roller-plates are to be so stiffened that the extreme fibre stress under bending, when impact is included, shall not exceed sixteen thousand (16,000) pounds for carbon steel and twenty-six thousand (26,000) pounds for nickel steel having an elastic limit of fifty-five thousand (55,000) pounds per square inch, with proportionate increase for greater elastic limit.

Pedestals shall be either of cast steel or built up of plates and shapes, preferably the former. In built pedestals all bearing surfaces of the base plates and vertical bearing plates must be planed. The vertical plates must be secured to the base by angles having at least two rows of rivets in the vertical legs; and the said vertical plates must bear properly from end to end upon the base. No base plate, vertical plate, or connecting angle shall be less in thickness than three-quarters (¾) of an inch. The vertical plates shall be of sufficient height and must contain enough metal and rivets to distribute properly the loads over the bearings or rollers. No metal less than three-quarters (¾) of an inch in thickness shall be used in cast-steel pedestals. The bases of all cast-steel pedestals shall be planed so as to bear properly on the masonry or the rollers. All rollers and the faces of base plates in contact therewith are to be finished smooth, so as to furnish perfect contact between rollers and plates throughout their entire length. All pedestals, whether built or cast, must have one or more diaphragms between webs, carried up as high as the general detailing will permit, so as to transmit transverse horizontal thrust to the base without overstressing the webs by bending in their weakest direction. Pedestals must not be allowed to hold water. If practicable, their boxed spaces are to be filled with rich concrete.

72. *Details of Design for Riveted-Truss Highway Spans*

In general, the rules given for the detailing of riveted-truss railway spans are to be adhered to in the detailing of riveted-truss highway spans, with the following possible exceptions:

In cheap highway bridges the lateral diagonals may be made of adjustable rods with right-and-left clevises at their ends, by which they are to be connected through pins to corner-plates that are riveted to both the lateral strut and the truss member. The unscientific detail consisting of two or three short pieces of angle iron riveted on top of the cover-plate, and between two of which the rod lies, will not be permitted. Where adjustable rods are employed, the struts to the ends of which they attach must be figured for a total compressive stress equal to the sum of the components (in the direction of the said strut) of the greatest allowable working-stresses on all of the adjustable rods meeting at one end of said strut. While this method gives an excessive stress for the strut, the effect will be a desirable error on the side of safety and rigidity.

Where built stringers are used for the floor system, they shall be

made without cover-plates, and generally of the economic depth in respect to total weight of metal, but never less in depth than one-fifteenth ($\frac{1}{15}$) of the span. Where such stringers are employed, the lower lateral system must invariably consist of rigid sections, each piece being riveted to each stringer where it crosses the same, if practicable.

The smallest section for a lacing-bar shall be one and three-quarters ($1\frac{3}{4}$) inches by five-sixteenths ($\frac{5}{16}$) of an inch, and the smallest section for any lacing-angle $2\frac{1}{2}'' \times 2'' \times \frac{5}{16}''$. No pin is to have a smaller diameter than four (4) inches. The least allowable diameter for expansion rollers is four (4) inches.

73. *Details of Design for Pin-Connected Railway Spans*

The detailing of pin-connected railway spans is to follow in general the specifications previously given for the detailing of riveted-truss railway spans, with the following exceptions:

The sections of the top chords and those of the inclined end posts of through-spans shall consist, generally, of two built channels and a cover-plate, each channel being formed of a web and two angles, the upper one small and the lower one much larger, so as to bring the centre of gravity of the entire box section of the member as close as possible to the mid-plane of the web-plates. In no case will more than one cover-plate be allowed, and this is to be made as thin as is proper. It is permissible to substitute rolled channels for the built ones; but when this is done it is often advisable to rivet a thick narrow plate to the under side of each channel, in order to facilitate the packing and detailing of web-members by keeping the centre line of stress as nearly as may be coincident with the mid-depth of the piece.

Main vertical posts shall, generally, be composed of two laced channels, preferably rolled ones, although built ones must be used where large sections are required. Secondary vertical posts may be built of two rolled channels laced, or of four angles in the form of an I with either a single line of lacing or a web. These secondary vertical posts should, preferably, be riveted to the top chord instead of being pin-connected like the main vertical posts. The channels of vertical posts may have their flanges turned either inward or outward, as desired, or so as best to suit the general detailing of the truss.

Stiff bottom chords and inclined web-struts may be made of either two channels with two lines of lacing or four angles with one line of lacing, the use of trussed eye-bars for struts being prohibited, as is also the use of counters.

Eye-bars are to be employed for all bottom chords and main diagonals that do not require to be stiffened.

Pin-plates shall be used at all pin-holes in built members for the double purpose of reinforcing for the metal cut away and of reducing the inten-

sity of pressure on pin and bearing to or below the specified limit. They shall be of such size as to distribute properly through the rivets the pressure carried by such plates to both flanges and web of each segment of the member; and they shall extend at least six (6) inches within the tie-plates of said member, so as to provide for not less than two (2) transverse rows of rivets there.

When the pin ends of compression-members are cut away into jaw-plates or forked ends, for the purpose of packing closely the various members connected by the pin, these jaw-plates or post extensions shall be considered as columns, the thickness of each of which shall be determined by the unit stresses previously specified, viz.:

$$p = 10{,}000 - \frac{300\,l}{t} \text{ and } p = 16{,}000 - \frac{500\,l}{t}$$

for carbon steel and nickel steel respectively; where p is the greatest allowable intensity of working stress (impact being considered), l is the unsupported length in inches, measuring from the centre of the pinhole to the centre of the first transverse line of rivets beyond the point at which the full section of the member begins, and t is the total thickness in inches of one jaw. The length l is always to be made as small as practicable; and, in cases of unavoidably long extensions, the plates are to be stiffened by an interior diaphragm composed of a web with four, or sometimes only two, angles. The greatest allowable value of l over t is twenty (20), l being the greatest unsupported length of the jaw-plate. It is always better, whenever practicable, to avoid cutting away the ends of channels; but, if they have to be trimmed, the ends must be reinforced so that the strength of the member will not be reduced by the trimming.

Riveted tension members with pin connections must have a net section back of the pinhole at least equal to the net section of the member, and a net section through the pinhole at least forty (40) per cent greater than the net section of the member; and there must be sufficient rivets employed to make all the material effective.

Pins are to be proportioned to resist the greatest shearing and bending produced in them by the members which they connect. No pin is to have a diameter less than eight-tenths ($^8/_{10}$) of the depth of the deepest bar coupled thereon, nor less than five (5) inches in any case.

Lower chords are to be packed as closely as possible, and in such a manner as to produce the least bending moments on the pins; but adjacent eye-bars in the same panel must never have less than a one-half ($\frac{1}{2}$) inch space between them, in order to facilitate painting. The various members attached to any pin must be packed as closely as practicable, and all interior vacant spaces must be filled with steel fillers, where their omission would permit of motion of any member or of the pin. All bars are to lie in planes as nearly as possible parallel to the central truss plane,

no divergence exceeding one-eighth (1/8) of an inch to the foot being permitted.

Heads of eye-bars are to be made of such dimensions that when the bars are tested to destruction they shall break in the body and not in the eyes.

74. *Details of Design for Pin-Connected Highway Spans*

In general, the rules given for the detailing of riveted and pin-connected railway spans and riveted highway spans are to be adhered to in the detailing of pin-connected highway spans, with the following possible exceptions:

Counters, when employed, can be of either rounds, squares, or flats. These and all other adjustable members are to have their ends enlarged for the screw-threads, so that the diameter at the bottom of the thread shall be one-eighth (1/8) of an inch greater than that of the body of a round rod of area equal to that of the adjustable piece.

No pin is to have a less diameter than four (4) inches.

Heads of eye-bars are to be made of such dimensions that, when the bars are tested to destruction, they shall break in the body and not in the eyes; and in the case of loop-eyes, so that they shall not fail in the welds. Rods with bent eyes shall not be used. In loop eyes, the distance from the inner point of the loop to the centre of the pinhole must not be less than two and one-half (2½) times the diameter of the pin, and the loop must fit closely to the pin throughout its semi-circumference.

75. *Details of Design for Railway Trestles and Elevated Railroads*

Trestles and viaducts shall consist of girder spans supported on trestle bents and at intervals on towers composed of two bents braced together longitudinally. Each bent shall consist of at least two columns, either vertical or inclined, braced together transversely to the structure.

The sections of main members of trestles shall generally be as follows:

Columns—two channels laced with flanges turned either out or in, two rolled or built channels with I-beam web between, four Z-bars with web-plate, four Z-bars with a single line of lacing inside and occasional stay-plates outside, or four angles with a single line of lacing inside.

Diagonals in transverse and longitudinal bracing and all bottom horizontal bracing struts—four angles with a single line of lacing.

Horizontal transverse bracing struts at top of towers—bracing frames of angles.

Longitudinal struts at top of towers—plate-girders.

Longitudinal girders—plate-girder spans, or occasionally, for very long spans, riveted trusses.

The detailing for longitudinal girders of trestles and elevated railroads and the bracing between the same shall comply with the specifications

governing the designing of plate-girder spans and the floor systems of riveted spans. In general, the transverse and longitudinal bracing of trestle towers shall consist of a double-cancellation system of stiff diagonals with horizontal struts. The latter at pedestals must be strong enough to move the column feet upon their sliding bearings when the struts are expanded or contracted by changes of temperature. Provision must be made for holding some feet rigidly, and for sliding some in one horizontal direction only and others in any horizontal direction, at the same time holding them all down so that they shall not be lifted perceptibly by the wind pressure. Sliding-plates are nearly always preferable to rollers for pedestals of trestles. They shall be planed extremely smooth, and so as to bear properly at all parts. Occasionally, in solitary bents, it is permissible to use hinged ends for columns at pedestals; but it is generally better to make them fixed, and to figure the columns for the greatest bending produced in them by transverse loads and extreme changes of temperature.

The batter of the columns should, generally, be not less than one and a half ($1\frac{1}{2}$) inches to the foot and not more than three (3) inches to the foot. When practicable within these limits, the trestle bent should have such a batter or spread of base as is necessary to meet the condition of no tension on the windward leg—otherwise the tension must be properly provided for.

The tops of trestle columns are to be made vertical by bending them beneath the longitudinal girders where the latter are riveted to them; and the upper transverse struts must be made as deep as the longitudinal girders, and must be riveted effectively to the columns. Corner brackets of double webs are to be used for connecting the columns to the horizontal struts and bracing diagonals, and at the same time to strengthen the column at the bend. Additional strengthening is to be given by using a solid web or diaphragm in the column, extending from the top thereof to a point about two (2) feet below the bend. All splices in columns are to be full, butt splices, located preferably about two (2) feet above the points where the sway diagonals connect, shingle-splicing being avoided because of the trouble it gives during erection. The splice-plates shall be figured to develop sixty (60) per cent of the section of the column; but care must be taken that the maximum bending stresses are fully provided for.

Whenever practicable, the span lengths for trestles are to be those which make the total cost of structure a minimum, the tower length varying from twenty (20) feet for low trestles to forty (40) feet or even more for very high ones, and the intermediate spans varying from thirty (30) to about eighty (80) feet. Any length of girder exceeding eighty (80) feet might necessitate either the employment of a traveller that would be too long, heavy, and expensive, or the use of bents of falsework between the towers.

For elevated railroads the sections of main members shall be as follows:

Longitudinal girders—preferably plate-girders, or, if necessary, open-webbed, riveted girders.

Cross-girders—plate-girders.

Columns for structures without longitudinal or tower bracing—two rolled or built channels with an I-beam riveted between.

Columns for structures with longitudinal or tower bracing—four Z-bars with a web-plate.

All columns for elevated railroads are to have both ends fixed, being held rigidly at the top by either the longitudinal girders or by deep struts that carry the thrust of braked trains from the track to the columns, and their sectional areas are to be figured accordingly for both direct load and bending.

Longitudinal girders in elevated railroads shall, generally, be riveted into the cross-girders and not rest thereon, except under certain conditions for the sake of clearance beneath, in which case the top flanges of the half-through girders must be stayed at the ends and at intermediate points, as specified for plate-girder spans. On all curves in elevated railroads, special lateral bracing of angles, riveted at intersections to the longitudinal girders and carried over and riveted to the columns, must be employed. Shelf angles for facilitating erection are to be provided on columns for the temporary support of the girders and in any other places where their use would expedite the work.

In general, the limiting length of structure between expansion points shall be about one hundred and fifty (150) feet. If this length be exceeded materially, the columns may have to be strengthened to resist the bending caused by changes in temperature.

All expansion-pockets are to be so detailed as to throw the load from the longitudinal girder as close as possible to the web of the cross-girder; and sufficient rivets are to be used in connecting the pocket to the cross-girder or column to provide for both the direct shear and the bending moment from the eccentric load; and the cross-girder or column is to be thoroughly riveted to the adjoining longitudinal girder so as to care properly for the bending or to avoid torsion.

All anchor bolts at column feet are to extend well up above the base-plate, passing between two angles that are riveted to the column, and which support a heavy washer-plate or angle to receive the anchor-bolt nut. All column feet are to be raised so far above the ground that no dirt, snow, nor moisture can collect around them and remain there. The boxed spaces at column feet are to be filled with Portland cement concrete made with small broken stone.

The bases of pedestals are always to be made large enough to prevent all possibility of settlement of foundations. In figuring the pressure on the base of the pedestals it is not sufficient to recognize only the direct

live and dead loads, but it is necessary also to compute the additional unequal intensities of loading by both longitudinal and transverse thrusts.

76. *Details of Design for Highway Viaducts*

The specifications for the "Details of Design for Railway Trestles and Elevated Railroads" and those for the "Details of Design for Highway, Plate-Girder Spans" are in general to be followed as far as they will apply in the designing of highway viaducts, the principal variation being that, for cheap structures, adjustable rods with clevises may be substituted for the stiff diagonals in the four faces of the braced towers. The struts must be riveted to the columns by means of wide plates to which the clevises attach, and must never be pin-connected.

The detailing for the longitudinal girders of viaducts and the bracing between the same shall comply with the specifications for detailing highway, plate- or open-webbed riveted-girder spans; and the specifications for wooden floor system, paving, hand-rails, etc., shall be the same for highway viaducts as for highway bridges.

77. *Swing Spans*

The following types of structure are to be used for railway swing spans:

For spans up to two hundred (200) feet in length—plate-girder bridges, acting as continuous girders over the pivot pier.

For spans between two hundred (200) feet and four hundred (400) feet —riveted truss bridges.

For spans exceeding four hundred (400) feet—either riveted or pin-connected bridges.

For spans up to about three hundred (300) feet it is best to make the top chords horizontal throughout, and beyond that length either to make them polygonal or to provide a tower at mid-span.

It is understood that these limiting lengths are not fixed absolutely, as the best limits will vary somewhat with the number of tracks and the weight of trains.

For highway swing spans the following types of structure are to be employed:

For spans up to one hundred and fifty (150) feet in length—plate-girder spans, acting as continuous girders over the pivot-pier.

For spans between one hundred and fifty (150) and three hundred (300) feet, riveted trusses are to be used.

For spans of over three hundred (300) feet, either riveted or pin-connected trusses with subdivided panels may be adopted.

It is understood that these limiting lengths are not fixed absolutely, as the best limits will vary somewhat with the width of bridge and the live load to be carried.

Swing spans may be either rim-bearing or centre-bearing.

The height of the towers should generally be between one-sixth ($\frac{1}{6}$) and one-seventh ($\frac{1}{7}$) of the total length of span, measuring from centre to centre of end-pins; although in certain cases it may, for the sake of appearance, be made a little greater. The truss depth at the inner hips should be from one-ninth ($\frac{1}{9}$) to one-tenth ($\frac{1}{10}$) of the total length of span. The truss depth at outer hips for spans up to four hundred (400) feet will generally be determined by the clearance required. For longer spans it should be between one-fourteenth ($\frac{1}{14}$) and one-fifteenth ($\frac{1}{15}$) of the total span-length. The least allowable perpendicular distance between central planes of trusses shall be one-twenty-fifth ($\frac{1}{25}$) of the total length of span.

The length of the centre panel in rim-bearing draws will, in most cases, be made equal to the perpendicular distance between central planes of trusses. In spans having horizontal top chords, all panels of the latter must be composed of stiff members, except the two central panels in pin-connected trusses. Broken top chords must be made of stiff members from ends to inner hips, but the portion between the inner hips may be of eye-bars. Inclined posts extending from the inner hips to the drum are to be used in all cases where the top chords are broken and where the structure is rim-bearing.

The loads to be considered in designing swing spans are the following:

A. Live Load.
B. Impact Due to Live Load.
C. Dead Load.
D. Impact Due to Dead Load.
E. Uplift at Ends.
F. Direct Wind Load.
G. Indirect Wind Load or Transferred Load.
H. Unbalanced Wind Load on One Arm only.
I. Vibration Load.

The live load for trusses with only one arm loaded is to be taken from the live-load curves for a span equal to the distance between the centre of the end-pin and the centre of the nearer tower post; but for both arms loaded the live load is to be taken for a span equal to the distance between centres of end-pins. For only one arm loaded, the half-span is to be considered to act as a simple span on two supports; and for both arms loaded, the entire span is to be considered continuous over four supports for a rim-bearing draw and over three supports for a centre-bearing draw. The stresses due to the live load, with both arms wholly or partially loaded, are to be determined by the balanced-load method. For convenience in determining the reactions at ends and at centre supports the curves shown in Fig. 29*a* can be used for rim-bearing spans and those in Fig. 29*b* for centre-bearing spans. The former gives, for balanced loads, the proportion of the load in one arm that is supported at its outer

end; while the latter gives the reactions on the three supports for a load of unity placed anywhere in either arm.

In spans of over three hundred (300) feet, the dead load per truss is to be increased properly from the ends toward the centre of span in order to cover the weight of the heavy truss-members, which increase in size toward the centre of the span. The dead loads from tower, drum, and turntable are not to be considered as affecting the stresses in the trusses.

The impact due to dead load is to be taken as twenty-five (25) per cent of the said dead load.

The wind loads per lineal foot of span for both the loaded and the unloaded chords when the draw is closed are to be the same as those specified for fixed spans, and only one-half as great when the draw is open, the length of span used, however, being that of one arm of the draw. They are to be taken from the curves in Figs. 9*b* and 9*d*. When the span is open, all the wind load is to be carried to the drum through the lateral systems. When the draw is closed, the wind load is to be carried to both the ends and the centre supports. In case a lateral system and the adjacent chords be considered to act as a continuous girder over the centre supports, the reactions at the ends and at the centre can be taken from the curves in Figs. 29*a* and 29*b*.

In the case of trusses with broken top chords, the wind load on the upper chords is to be assumed to travel through the upper lateral system to the inner hips when the span is open, then down the inner inclined posts to the drum, thus producing a transferred load on the leeward inclined post and a released load on the windward one. As the upper lateral system is not to be made continuous between the inner hips, none of the wind load on the upper lateral system will be carried down the tower-posts, excepting only that which comes on the centre panel and the two adjacent panels. In order to ensure such a distribution of the wind load, diagonals must not be put in those panels of the upper lateral system which are adjacent to the inner hips and between these and the tower. The stresses in the chords between the hips from both the direct and the transferred wind load shall be duly figured.

In the case of trusses with parallel chords, the wind load on the upper chords is to be assumed to travel through the upper lateral system to the tower posts when the span is open, then down the tower posts to the drum, thus producing a transferred load on the leeward tower post and a released load on the windward one.

When the draw is closed, for trusses with either broken top chords or parallel chords, one-half of the wind load on the upper lateral system of one arm is to be assumed to travel down the outer inclined posts, and one-half down the inner inclined posts or the tower posts, as the case may be—the proper transferred and released loads being figured in all cases. A vertical unbalanced wind load of ten (10) or

fifteen (15) pounds per square foot shall be assumed as acting upward on the entire bottom area of one arm only when the span is swinging, the exact amount depending on the relative exposure of the structure to high wind pressures; and the span must be so anchored as to care properly for this load.

The vibration load, which applies to railway spans only, is to be as specified in clause 44.

In ascertaining the stresses in the trusses of swing-bridges the following conditions are to be considered:

Case No. 1. Greatest stresses, dead load only acting, bridge open.

Case No. 2. Greatest stresses, dead-load impact only acting, bridge open.

Case No. 3. Greatest stresses from assumed uplift at end of span.

Case No. 4. Greatest stresses from live load on one arm only; each arm being considered to act as a simple span on two supports, the usual allowance for impact being made.

Case No. 5. Greatest stresses from live load on both arms, the live load advancing from both ends toward the centre until the span is fully loaded; the latter being considered to act as a continuous girder over four supports for a rim-bearing span and over three supports for a centre-bearing span.

Case No. 6. Greatest direct stresses, on the chords that carry the live load, from wind load when the bridge is open.

Case No. 7. Greatest direct stresses, on the chords that carry the live load, from wind load when the bridge is closed and wholly or partially loaded.

Case No. 8. Greatest indirect wind-load stresses or transferred-load stresses on the lower chords when the bridge is closed and wholly or partially loaded.

The first combination of these stresses includes Cases No. 1 and No. 2; and it gives the greatest stresses for all truss members from dead load and dead-load impact, when the span is swinging. The second combination includes Cases No. 1, No. 3, No. 4, and No. 5, and gives the greatest stresses for combined live and dead loads. It is to be noted that, as previously stated herein, wherever the load for Case No. 3 increases the total stress on any member, its effect is to be considered; but wherever the said load decreases the total stress on any member, its effect is to be ignored. The regular specified intensities of unit stresses are to be used for both the first and second combinations.

The third combination of these stresses includes Cases No. 1, No. 2 and No. 6, and gives the maximum stresses, including wind, when the span is open. The fourth combination includes Cases No. 1, No. 3, No. 4, No. 5, No. 7 and No. 8, and gives the maximum stresses, including wind, when the span is closed. For the third and fourth combinations, the metal may be stressed thirty (30) per cent higher than for the first and second combinations. It should be noticed, however, that the only truss

members affected by the wind loads are the inclined posts at the ends and over the drum, and the chords which carry the live load.

For the lateral systems the following conditions are to be considered:

For upper lateral systems of through-bridges and lower lateral systems of deck-bridges.

Case No. 1. Greatest wind-load stresses when span is swinging.

Case No. 2. Greatest wind-load stresses when span is closed and ends are raised, thus making the upper lateral system of each arm with the top chord a simple span, and making the entire lower lateral system with the bottom chords a continuous girder over four points of support for a rim-bearing span, and over three points of support for a centre-bearing span. This case does not involve the presence of any live load on the spans.

Case No. 3. Greatest vibration load stresses under conditions like those in Case No. 2.

For lower lateral systems of through-bridges and upper lateral systems of deck-bridges.

Case No. 4. Greatest wind-load stresses when span is swinging.

Case No. 5. Greatest wind-load stresses when span is closed and ends are raised, and with live load on one arm only, thus making the loaded chords with their lateral system a simple span with supported ends.

Case No. 6. Greatest wind-load stresses when span is closed and ends are raised, and with the live load on both arms covering same either wholly or partially, thus making the loaded chords with their lateral system a continuous girder with four (4) points of support in the cases of a rim-bearing span and with three (3) points of support in the case of a centre-bearing span.

Case No. 7. Greatest vibration load stresses under conditions like those in case No. 5.

Case No. 8. Greatest vibration load stresses under conditions like those in Case No. 6.

The greatest stress on any lateral member found by these eight conditions of wind-loading is to be used in proportioning its section, and there is to be assumed no division of the wind load between structure and train, although the failure to make the said division will cause small errors on the side of safety.

78. *Special Details of Design for Plate-Girder Swing-Spans*

Plate-girder swing-bridges are to be made as continuous beams over three or four points of support—preferably over three. They may be either rim-bearing or centre-bearing. The same combinations of stresses are to be used as specified for truss draw-spans, but it will generally be found that the wind loads do not affect the proportioning of the girders. In general, the specifications for the detailing of fixed plate-girder spans are to govern the designing of plate-girder draw-spans, except as hereinafter stated.

In deck, plate-girder draw-spans the girders are to be spaced the same distance apart as specified for fixed plate-girder spans of one-half the length. For half-through, plate-girder draw-spans the girders may be spaced as closely as the previously specified clearance requirements will permit. For deck-spans four points of support on the drum will suffice, but for half-through spans eight points will be required. The diameter of the drum is to be made as small as practicable, but never less than eight (8) feet; and the distribution of the load over the drum is to be uniform. All girders are to be thoroughly stiffened at all points of bearing over the drum, and bearing-plates not less than one (1) inch in thickness are to be used between the drum and all girders bearing thereon.

When the length of span over all exceeds one hundred (100) feet, it will be necessary to splice the main girders in the field. These splices must be thoroughly made, shingle or staggered splices only being allowed; and there must be ten (10) per cent excess of strength in the details at all points thus spliced, as previously specified for fixed plate-girder spans.

Rigid bracing-frames are to be used between main girders of deck-spans at the points where the main girders bear on the drum; and heavy, rigid, plate cross-girders resting on the drum are to be used for half-through spans.

79. *Special Details of Design for Trusses of Swing Spans*

The details of trusses for swing-spans shall comply in general with the specifications given for trusses of fixed spans. In pin-connected trusses having broken top chords, that portion of the said chords between outer and inner hips is to be made of rigid members, and that portion between the inner hips and over the tower is to be made of eye-bars. In pin-connected trusses with parallel chords, rigid members will be required throughout the top chord, except for the centre panel, in which eye-bars may be used. In riveted trusses stiff top chords from end to end of span are to be adopted. Ample provision for adjustment of elevations of ends of span shall be made by means of shimming plates of various thicknesses at each end-bearing.

Rigid portal-bracing attached to both the upper and the lower flanges must be used between the two inclined posts at both the inner and the outer hips. These portals are to be carried down as low as the specified clearance over tracks will permit.

The tower must be rigidly braced in all four faces. In the transverse planes all the diagonals and horizontal struts must, generally, be made of stiff members of box or I-section, so as to take hold of the exterior of the posts; and this sway-bracing must be carried down as low as the specified clearance will permit, in order to hold the tower posts firmly to place and line. In the planes of the trusses the diagonals are to be made of stiff members having ample section to provide for any possible unequal

vertical wind-pressure when the span is open; and the horizontal struts are to be of box or I-section. A pair of rigid struts must be used in the horizontal plane of each vertical panel of tower bracing, so as to ensure the permanent rectangularity of the section of the tower.

The upper lateral system between the inner and the outer hips and in the tower panel is to be made of rigid diagonals, capable of taking both tension and compression, and transverse struts of I-section that are securely riveted to both the upper and the lower flanges of the top chords.

The transverse sway-bracing between trusses is to be made entirely of rigid members, and is to be carried down as low as clearance requirements will permit. In long spans the lower horizontal struts of the vertical sway-bracing must take hold of the vertical posts at the flanges of same so as to hold the said posts firmly in position.

80. *Camber and Deflection of Swing Spans*

The lengths of all truss members shall be such that when the assumed uplift is applied by the wedges at the ends of the span, and when the greatest live load is on the structure, the centre lines of the bottom chords from end to end of span will lie in a horizontal plane. The vertical movement of the ends from the condition of no stress in the chords, when the weight of the finished span is supported on the falsework, to the condition of the span swung, must be very carefully figured, as upon this will depend the camber increments or decrements in lengths of members, the clearances, the adjustments, etc. Due allowance shall be made for the top chord's having a temperature 30 degrees F. greater than the bottom chord.

81. *Details of Drum and Loading Girders for Rim-Bearing Swing Spans*

The drum must be strong and deep enough to distribute the total load from the span properly over the rollers. In general, it should be made, within reasonable limits, as deep as possible, and not less than one-half of the greatest distance between adjacent points of loading; for the cost due to the extra depth will be more than offset by the saving in height of pivot-pier. The bending moment on the drum is to be computed by the compromise formula,

$$M = \frac{1}{10} Wl;$$

where M = bending moment in foot-pounds, W = greatest load in pounds on one point of bearing on drum, and l = distance in feet between points of bearing. The drum is to be designed according to the specifications for ordinary plate-girders. The web thereof shall have stiffeners on both sides at all points of concentration. These stiffeners must have perfect contact with the top and bottom flanges. The section required for these stiffeners is to be determined by considering the entire concentration on one point of bearing to be carried by the said stiffeners, which act as a

column, fixed at both ends, with an unsupported length equal to the depth of drum. The bearing area of the outstanding legs must also be adequate for the load carried. Stiffeners, each consisting of two angles, placed on opposite sides of the web, must be used at intermediate points at distances not exceeding either the depth of web, or three (3) feet six (6) inches. Fillers are to be used beneath all stiffeners.

Brackets to support the pinions gearing into the rack are to be provided on the drum and are to be securely riveted thereto. They shall be built of rolled-steel sections, and made amply strong in all directions and in every particular so as to resist the greatest thrust, wrenching, or torsion that can possibly come from the shaft. In no case are such brackets to be made of castings. The use of turned bolts for attaching the brackets to the drum will not be permitted where it is possible to drive rivets, as such bolts do not afford sufficient rigidity to prevent the connections from working loose sooner or later.

The splices in the web and flanges of drum must be such as to develop the full strength of same; and the abutting ends of web and flanges must be planed smooth so as to have continuous contact. The drum must be made perfectly round, so that the centre line of web at any height will conform to the circumference of a circle; and to preserve this form and brace the drum thoroughly, rigid radial struts are to be run from the centre casting to the drum, taking hold of the latter at each point of concentrated loading and at intermediate points when the bearings are spaced more than eight (8) feet between centres. These radial struts must be made of four angles with solid webs or angle-lacing. At the centre they are to be riveted to circular plates fitting closely around the centre casting, thus anchoring the drum firmly to the latter. Oil-grooves must be provided where these plates bear on the centre casting.

The drum must be assembled and the bottom must then be planed smooth so as to provide an even bearing for the upper track. If it is not practical to plane the entire drum at once, then each segment thereof is to be planed separately; but in this case the greatest care is to be taken to make the assembled parts form a perfect whole. The least thickness of metal to be used for bottom flanges of drum shall be three-quarters (¾) of an inch for railway spans and five-eighths (⅝) of an inch for highway spans, so as to provide ample metal for planing off the bottom; and that for the web and top flanges, one-half (½) inch for railway spans and three-eighths (⅜) inch for highway spans.

Spans resting on drums of small diameter in proportion to the span length are to be anchored to the pivot-pier by means of a large anchor-rod in centre of pier, extending down ten (10) or fifteen (15) feet into same. This rod shall pass through the centre casting and through a box-girder over the centre of the drum, which girder shall rivet into either the transverse or the longitudinal girders. The lower end of the rod shall pass through a heavy cast-iron anchor-piece embedded in the con-

crete of the pier. Both ends of the rod shall be provided with nuts for adjustment, and all details shall be made strong enough to develop the full strength of the anchor-rod. The upper nut shall be almost, but not quite, in contact with a large washer-plate that rests on the box-girder. The anchor-rod shall be proportioned to resist the effects of the assumed wind loads.

The girders over the drum shall be so arranged as to distribute the load over it properly. The number of bearing points required will depend upon the length of span, the distance from centre to centre of trusses, the total load to be carried, and the economical size of pivot-pier. The arrangement of the supporting girders in turn depends upon the number of bearing points to be used. For ordinary, single-track-railway bridges up to three hundred (300) feet in length a very good arrangement of girders over drum is secured by making the diameter of the drum and the length of centre panel equal to the distance from centre to centre of trusses; then the middle points of both the longitudinal and the transverse girders will be directly over the web of the drum, thus furnishing four points of bearing. Four more points are secured by putting in short diagonal girders, which connect to both the transverse and the longitudinal girders and bear on the drum at their centres. This arrangement gives in all eight (8) points of support. The longitudinal, transverse, and diagonal girders over the drum shall be so designed that their rigidities will be such that when deflected under the load the extreme fibre-stress will be about the same in all the said girders.

The bottom-chord stresses in the centre panel can be carried by the longitudinal girders, or the bottom-chord sections can be continued through the centre panel, the longitudinal girders being placed above them, and steel chairs being inserted beneath their centres to furnish bearings on the drum. In case the bottom-chord stresses are carried by the longitudinal girders, ample provision must be made for them, as well as for the bending stresses, in designing the sections for these girders. Where the clearance over the waterway will permit, metal can be saved by letting the top flange of the longitudinal girder form the bottom chord of the truss.

In single-track spans of three hundred (300) feet or over, and in double-track spans of two hundred (200) feet or over, cast-steel ball-and-socket bearing-blocks are to be used between the top flange of the drum and the bottom flanges of the girders, in order to make definite the points of concentration, and so as to transmit the load properly from girders to drum. For smaller spans, bearing-plates, at least one (1) inch thick for railway structures and three-quarters (¾) of an inch thick for highway structures, may be substituted for the ball-and-socket blocks.

All girders bearing on the drum are to have stiffeners on both sides of their webs at all points of concentration; and in no case are the stiffeners to be crimped, but are to have fillers beneath. They must have

close bearings at top and bottom flanges; and they are to be proportioned in the same manner as previously specified for those on the drum.

82. *Supporting Girders for Centre-Bearing Swing Spans*

In centre-bearing draws the dead load shall generally be carried by a system of girders supported on top of the centre casting. Four rolled or built-up beams running transversely to the axis of the bridge shall be supported directly on and securely bolted to the upper part of the centre casting. Suspended from these beams shall be two pairs of beams, one on each side of the centre casting, parallel to the axis of the bridge and riveted to two cross-girders, one on either side of the centre casting placed as close together as practicable. All beams shall be designed particularly for rigidity so that the amount of deflection in them will be inappreciable. The suspenders shall generally consist of four (4) rods with nuts at each end. In small spans when there is sufficient clearance, the cross-girders may be supported directly on the centre casting, or the supporting beams may be run longitudinally and riveted directly to the cross-girders. But, as a rule, the suspended system is preferable on account of the possibility of adjustment.

The live load shall be carried on wedges at the centre of the span and shall be transferred to the said wedges by longitudinal beams riveted to the cross-girders.

The span shall be supported during rotation by six or eight trailing wheels in bearings attached to the trusses at the sides and to special structural frames at intermediate points. All parts must be designed for the wind loads on them due to the tendency of the span to overturn about its centre.

The top of the pivot-pier is to be levelled off with neat Portland-cement mortar, and the lower track is to be set in same. It shall be made one and one-half ($1\frac{1}{2}$) or two (2) inches higher in the centre than at the edge, so that the water will drain toward the latter. A small gutter or depression in the top of the pier is to be made just inside of the lower track, and at the bottom of this depression drain-holes are to be put in, leading the water from the gutter down on the outside of the pier. These drain-holes are to be at least three (3) inches in diameter, and the tops are to be protected with screens, so as to prevent choking. They are to be spaced not to exceed ten (10) feet between centres.

83. *Lift Spans*

In general, the preceding specifications for fixed and swing spans shall govern the design of lift spans. The following special points shall, however, be considered.

The operating machinery and the machinery-house shall be placed at the centre of the span. In truss spans the house shall be located

above the top chords, or between the trusses below the top chords if the truss depth is sufficient to permit this construction. In deck-girder spans the machinery shall generally be placed between the girders below the deck. In half-through plate-girder spans, the machinery shall be placed either below the deck or outside of the girders. The machinery and house shall be supported on steel beams and girders framed into the trusses or main girders.

The suspending cables shall be connected either to the trusses or girders direct, or to lifting girders between the trusses or girders. In truss spans the lifting girders shall be framed into the trusses between the U_0 points, and shall generally consist of two leaves spaced so as to give proper connections for the ropes. In deck, plate-girder spans the lifting girders shall be framed between the main girders at the ends, and shall extend beyond the said girders on each side for the rope attachments.

Each tower for a short plate-girder span with a low lift shall consist of two single columns with transverse sway bracing, there being longitudinal overhead bracing between the two towers. For higher lifts and longer spans the overhead bracing shall be omitted, and the main tower columns shall be braced by back-legs attached to the adjacent spans or to masonry. These back-legs shall be sway-braced transversely and braced to the main columns longitudinally.

At the top of the tower the main tower columns shall be connected by the sheave-girder. This girder shall consist of either one or two leaves, depending on the weight to be lifted and the make-up of the main column section. Where the column is composed of four angles and a web-plate, either with or without side-plates, a single-leaf girder shall generally be used; and where it consists of rolled or built channels with the flanges turned in and connected by a diaphragm of four angles and a web-plate, a double-leaf girder shall be adopted. The back-legs shall be braced together at the top by a shallow, single-leaf girder; and side girders shall be employed between the main tower columns and the back-legs. Horizontal bracing shall be used between these girders.

As a rule skew crossings shall be avoided; but where this is impossible and a large skew exists, and where the towers are supported independently on masonry, they shall be built up of four vertical columns braced in all four vertical planes and in the top horizontal plane.

Where the towers consist of two columns braced by the back-legs, the sheaves shall generally be supported on the tower columns produced, and on subposts supported on top of the sheave-girder in case single-webbed girders are adopted, or riveted between the girders in case double-webbed girders are employed. In the former case, the subposts must be braced to the transverse girder between the back-legs. Where each tower consists of two columns alone or of four columns as in skew crossings the tower sheaves shall be supported on subposts riveted to the tower columns.

In ordinary towers only two sheaves shall be used, and the counter-

weights shall move up and down inside of the towers. In skew crossings or other crossings in which the tower consists of four main columns, four sheaves shall be employed, and the counterweights shall move up and down outside of the tower.

Rigid supports and connections shall be provided for all machinery parts.

84. *Bascule Spans*

Bascule spans shall, in general, conform to the preceding specifications for fixed and movable spans, and each type will have its own peculiar details to be worked out.

In highway bascule spans the floor construction shall be such that there will be no displacement of the floor when the span is in its raised position. This will generally require the use of a timber plank floor.

All parts of the moving span shall be designed for the stresses produced for any position of the span from the fully-open to the closed. Where the stresses are indeterminate as is the case in the counterweight arm of certain trunnion bascule spans, each member shall be figured for the greatest possible stress that may come on it under the most logical assumptions. Such members shall, preferably, have a section somewhat in excess of that required by theory.

The axles for trunnion bascules shall be made as rigid as practicable so as to reduce their deflections to the greatest extent possible. Proper provision shall be made at the points of support, as well as at the bearing points of the trusses, for the deflection of the axle.

In double-leaf bascules for highway bridges a substantial connection shall be provided between the ends of the two leaves.

85. *Structural Supports for Machinery*

All structural supports and connections for machinery shall be properly designed for the loads carried as well as for all stresses induced by the operation of the machinery; and an impact of one hundred (100) per cent shall be applied to the latter. The beams in the machinery-house shall be figured to support a load of 5,000 pounds, or the heaviest piece of machinery in the house, in addition to the load from the floor and the beam itself. The unit stresses employed shall be one-half (½) of those heretofore specified for ordinary structural work.

Power

86. *General*

In operating a movable span, either hand power or some kind of mechanical power must be employed, the determination of this point depending generally upon local conditions. Wherever the operation is very infrequent and where ample time for opening is available, hand power may

be used. But where that class of equipment alone is installed, it is necessary that men be easily procurable for operating the bridge, and the span must be opened and closed often enough to ensure keeping the machinery in good working condition. Where there is a possibility of requiring mechanical power in the future, provision should be made for the addition of such equipment.

In most cases it will be found advisable to employ some form of mechanical power; and, as a rule, either an electric or internal combustion motor will prove the most satisfactory. Wherever it is possible to obtain electric current, the electric motor should be adopted, otherwise the internal combustion motor. As a source of power storage batteries are rather unsatisfactory; and, unless called for by special considerations, they should be avoided. In all cases ample power shall be provided and emergency equipment installed. In certain cases hand operation may be satisfactory for the emergency equipment; but where conditions are such that it is impracticable, a gasoline engine shall be used. Suitable brakes must also be employed to stop and hold the span in any position under all conditions governing its operation.

In operating the span, the power equipment must be ample to overcome all resistances in the times specified for opening under various conditions. The forces to be overcome are friction, inertia of moving parts, wind, and in some cases certain unbalanced loads. The moving load shall be taken the same as is used in the designing of the structural work. In locations where snow is likely to occur during the open navigation season, proper provision must be made for taking care thereof in the design of power and machinery equipment.

For railway floors the area exposed to wind shall be taken at eighty-five (85) per cent of the gross area.

For spans where unusual wind conditions exist, especial attention must be given to the design of the operating equipment.

In determining the power required for all types of movable spans as well as in designing the machinery, the efficiency of a pair of spur gears shall be taken at ninety-three (93) per cent. This allows for journal friction. The efficiency of a set of bevel gears shall be taken at eighty-five (85) per cent., and of worm-gearing at fifty (50) to sixty-five (65) per cent.

The torque at the armature shaft required to overcome each force throughout the movement of the span shall be determined and given by curves, together with a curve showing the total or maximum torque at any time during the operation of the span.

87. *Swing Spans*

For centre-bearing swing spans the friction shall be taken at nine (9) per cent of the total load on the pivot; and for rim-bearing spans at six-tenths (.6) per cent of the load on the rollers. This force shall be assumed

to be located at the centre of the rollers in rim-bearing swings and at a point two-thirds of the radius of the disc from the axis of rotation in centre-bearing drawspans. Applied at the pitch line of the rack this force becomes:

$$F_1 = \frac{.06\ WR_1}{R} \text{ for centre-bearing swings,}$$

and $$F_1 = \frac{.0006\ WR_2}{R} \text{ for rim-bearing swings;}$$

where R_1 = radius of disc for centre-bearing swings,
R_2 = radius to centre of rollers for rim-bearing swings,
R = radius of pitch-line of rack,
and W = weight on rollers or disc.

The force at the rack to overcome inertia is

$$F_2 = \frac{Mar^2}{R^2};$$

where M = Total mass to be moved,
a = Lineal acceleration at pitch circle of rack,
r = Radius of gyration,
and R = Radius of rack.

For swing spans opening in from one (1) to one and one-half ($1\frac{1}{2}$) minutes, the period of acceleration should be taken at from ten (10) to twenty (20) seconds, and the period of retardation from ten (10) to fifteen (15) seconds.

For greater times of opening these periods should be increased in about the same proportion.

Ordinarily r^2 can be assumed equal to $\frac{a^2 + b^2}{3}$,

where a and b are the half-length and half-width of the span. Where the span is very long and there is considerable variation in the weight of the truss per lineal foot, the total weight at each panel-point should be figured and the radius of gyration, r, determined by assuming these weights concentrated at the centre line of truss.

Assuming $r^2 = \frac{a^2 + b^2}{3}$, and $M = \frac{W}{32.2}$ (where W is the weight corresponding to the mass M), the force at the rack to overcome inertia becomes

$$F_2 = \frac{Wa\,(a^2 + b^2)}{96.6\ R^2}.$$

An unbalanced wind load of one (1) pound per square foot shall be assumed to act on the exposed area of one arm of the span as seen in vertical projection. The centre of this load shall be taken at a distance

of $l/2$ from the axis of rotation, where l is the length of one arm of the span. The force at the rack to overcome this wind load is

$$F_3 = \frac{Pl}{2R},$$

where P is the total unbalanced wind load on one arm. This force shall be added to those for friction and inertia; and the power equipment must be capable of overcoming all these forces in the normal time of operation or the least time specified for opening. In the more important bridges this time should usually vary from one (1) to one and one-half (1½) minutes. Where the conditions so warrant, this limit may be increased according to the judgment of the Engineer. The machinery must also be strong enough to hold the span against an unbalanced wind load of ten (10) pounds per square foot. Special cases sometimes arise where one arm will be protected from the wind while the other is not, or one arm may be longer than the other, as in a bob-tailed draw. Such cases will have to be given special consideration when they arise.

In operating the end and centre wedges, the forces to overcome are the horizontal components of the vertical reactions on the wedges and the friction on each contact surface. This friction shall be taken at fifteen (15) per cent for each surface. In case toggles are used to lift the ends of the span, the friction in the toggle-joints shall also be taken at fifteen (15) per cent of the total load thereon. For operating the locks a proper allowance of power is to be made. The wedges and locks should be opened or closed in from fifteen (15) to thirty (30) seconds.

88. *Lift Spans*

For vertical lift spans the friction on the journal shall be taken as twelve (12) per cent at the start and reduced by unity for each increase in speed of one (1) foot per minute at periphery of journal until the friction has been reduced to six (6) per cent. This force shall be reduced to an equivalent force at the rim of the tower sheave. If r = the radius of the journal, R = the radius of the supporting sheave, W = total moving load, the force in the operating ropes to overcome starting friction becomes

$$F_1 = \frac{0.12\,Wr}{R}.$$

The force at any other instant shall be determined in the same way by using the proper friction factor.

The force necessary to overcome inertia is

$$F_2 = M\alpha = \frac{W\alpha}{32.2},$$

where W = total moving load, and α = the linear acceleration. For

spans opening in from one (1) to one and one-half ($1\frac{1}{2}$) minutes, the acceleration should take place in from ten (10) to twenty (20) seconds and the retardation in from ten (10) to fifteen (15) seconds. Where the time allowed for opening and closing is greater, the period of acceleration and retardation should be increased correspondingly. In lifting-decks, the time for opening should vary from one-half ($\frac{1}{2}$) to one (1) minute, and the time of acceleration should be decreased in due proportion.

Except when the span and the counterweight are at mid-height of lift, the counterweight ropes themselves are unbalanced. This condition may be overcome by special balancing chains; but when this is not done, the weight of the unbalanced rope must be taken care of by the operating equipment. The force necessary to overcome the effect of the unbalanced cables is

$$F_3 = R,$$

where R is the weight of the unbalanced cables at any point in the travel of the span. It must be remembered that for the first half of the operation in either direction this unbalanced load acts against the force tending to move the span, whereas in the latter half thereof it acts with that force and against the braking action.

For normal operation a wind load of two (2) pounds per square foot shall be assumed as acting against the exposed area of the span as it is seen in vertical projection. The friction on the guides due to this wind load must be overcome by the operating ropes. This friction shall be taken as fifteen (15) per cent of the said wind load.

For normal operation of from one (1) to one and one-half ($1\frac{1}{2}$) minutes the operating equipment must be capable of overcoming the above forces. It must also be capable of moving the span for all wind loads of less than fifteen (15) pounds per square foot, although the time of operation under such a condition shall be increased accordingly.

The span-locks for lift bridges shall, as a rule, be operated by hand, when the operator is located in the machinery-house. However, when mechanical operation is required therefor, it shall be designed to meet the case in hand.

89. *Bascule Spans*

For bascule bridges the power equipment will depend on the type of bascule used; and, in general, it will be governed by the preceding specifications for lift bridges. For rolling bascules the coefficient of rolling friction shall be taken at eight (8) per cent. The operating equipment on all types must be capable of holding the span in any position for a wind load of fifteen (15) pounds per square foot on the exposed surface as seen in vertical projection, and of moving it in the specified time against a wind load of two (2) pounds per square foot thereon.

POWER EQUIPMENT

90. *Hand Operation*

When hand power is used on the span, the number of men required and the time to operate shall be based on the assumption that one man can exert a force of 40 pounds on a lever with a speed of 160 feet per minute, developing about one-fifth of a horse-power. For figuring the strength of the machinery a man shall be assumed to exert a starting force of 125 pounds.

91. *Electric Operation*

The motors for performing the various operations necessary to open and close the movable span shall be of either A. C. (alternating current) or D. C. (direct current) construction, depending upon the kind of current available at the bridge site. For alternating current, crane or mill-type slip-ring induction, or railway motors shall be used; and for direct current, railway, crane, or mill type; series-wound motors with slotted-drum armatures and form-wound armature coils. All motors shall be weatherproof or protected by weatherproof housings so arranged as to permit easy access for inspection and repairs. The housings shall be tapped for conduits so as to avoid exposing the motor-leads. Standard commercial motors in common use shall be selected so that duplicate parts can be readily obtained. Motors entirely enclosed shall be provided with openings for inspecting commutator and brushes. The motor shall either have the armature shaft extended and key-seated for a coupling, or shall be provided with back gears. In the latter case a forged steel pinion shall be keyed and locked to the armature shaft and shall engage a cast-steel gear keyed to a secondary shaft with bearings in the motor frame. The secondary shaft shall be key-seated for a coupling, and the back gearing shall be properly housed. Both gears shall have machine-cut teeth.

For light spans one motor shall generally be employed to operate the span; but for heavy spans two motors, although one motor only may be used, if the engineer so decides. Where two motors are employed to operate the span in the normal time, provision shall be made for operating it in a longer time with one of the motors alone. With D. C. equipment the two motors shall be operated in series parallel. A separate motor shall be used to raise the ends of swing spans, and to operate the locks and gates where mechanical power is used therefor. The motors shall be capable of developing the necessary torque and horse-power required for performing the various operations within the times specified. Motors shall be rated on the one-half (½) hour basis, according to the Standard Rules of the A. I. E. E., viz.:

After one-half hour's run at the rated loads, the temperature of any

part of the motor windings shall not exceed by more than fifty (50) degrees C. that of the surrounding air, if the temperature of the surrounding air is twenty-five (25) degrees C. The permissible rise in temperature shall be increased or decreased one-half of one per cent for each degree centigrade that the surrounding air is less than or greater than twenty-five (25) degrees C. The normal running and starting torques and the maximum running and starting torques of the motors shall be obtained from the company or companies manufacturing the motors selected. For normal operation, the sum of the normal starting torques of the motors shall be slightly in excess of the starting torque needed to move the span, and the sum of the normal running torques at maximum speed required shall be slightly in excess of the running torque required at the end of the accelerating period. Where two motors operate the span, the maximum starting and running torques of each motor shall be well in excess of the total starting and running torques required. Under all conditions of operation there shall be no injurious heating or sparking of the motors. The speed of the motors throughout the operations shall be such as to open or close the span in the required time.

All motors shall be equipped with standard solenoid brakes with a braking torque that will stop operation in the required time. These brakes shall be set by springs or other mechanical means, and released by solenoids operating only when the motors are drawing current, except as hereinafter provided. The solenoids shall have ample capacity for all currents passing through the motors without exhibiting injurious heating. The friction surfaces shall be of materials not affected by moisture. To make coasting possible, a release shall be provided for each solenoid brake, allowing it to draw current when the motors are shut off at the will of the operator. Weatherproof motors shall be provided with weatherproof solenoids.

Motors shall be mounted so as to afford easy access for inspection and repairs. They shall be supported on good, substantial brackets or foundations. For each size of motor there shall be furnished the following extra parts: one armature, one set of field coils, one set of brushes, and one pinion and one split gear (if the latter two are supplied with the motor) fitted and ready for quick installation.

Controllers shall be of the reversing-drum type with contacts protected by blowout magnets, except where the currents are too large for the ordinary controller or where remote control is necessary, in which cases there shall be magnetic switches on the switchboard operated by master controllers. All controllers shall be of ample carrying capacity to operate the motors under all conditions without injurious sparking. They shall be capable of varying and maintaining the speed from zero at the start to the maximum running speed without injurious sparking or shock due to sudden variation in speed. Sufficient steps shall be provided on the controller so that the torque of the motor will vary approximately

as the torque required. The controllers shall be so wired that the solenoid brake will be released on the first notch and the motors started on the second. Where two D. C. motors are used, they shall be connected by one series parallel type controller, capable of operating both motors or either motor alone. Separate controllers shall be used for the end lifting, locking, or gate motors where electrical operation is provided. All apparatus shall be so interlocked that all operations can be performed only in their proper sequence. In railway bridges, emergency switches shall be provided so as to release the various motors from interlocking in case the interlocking system becomes deranged or in case there is not sufficient time to set the signals without great risk of a boat's striking the span. These switches shall be placed in sealed glass cases on the switchboard.

Cast grid resistances shall be used in the motor circuits, designed so as to carry the currents required without destructive heating. They shall be properly mounted so as to avoid serious vibration and so as to give proper access for ventilation and inspection.

In addition to the solenoid brakes, hand brakes shall be used for the main operating motors when the operator is located in the machinery-house; otherwise an electric brake shall be employed. The hand brakes shall be of the band type, and shall be operated by a lever located near the controllers. The brake shall have a braking torque equal to the normal starting torque of the motors. Hard maple blocks attached to steel bands shall bear on a cast-steel brake-wheel. The coefficient of friction between the blocks and the cast steel brake-wheel shall be taken at twenty (20) per cent.

The brakes shall be of the type shown in Fig. 78*a*. *O* is the centre or support of the brake wheel; *B* and *E* are the supports of the bell cranks

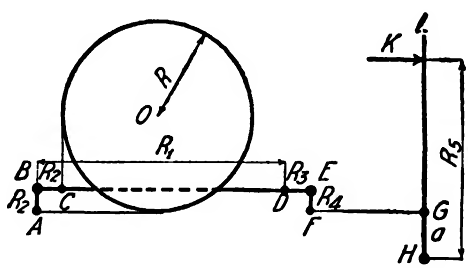

FIG. 78*a*. Hand Brake.

ABD and *DEF*, respectively; *A* and *C* are the points of connection of the brake-band to the bell crank *ABD*; *H* is the support of the lever *LH*, and *G* is the connection point for the link *FG*.

Let K = Force applied on the brake-lever.

P = Force at the circumference of the brake-wheel to be overcome.

R = Radius of the brake-wheel.

$T = PR$ = Torque to be overcome.
T_t = Pull in the brake-band on the taut side.
T_s = Pull in the brake-band on the slack side.

$$\lambda = \frac{T_t}{T_s}.$$

e = Base of the Naperian logarithms = 2.71828.
f = Coefficient of friction between the brake-wheel and the band-blocks.
θ = Angle of contact between the brake-band and the brake-wheel in radians.

Then $\lambda = e^{f\theta}$. (See Table 78*d*.)

$$P = T_t - T_s = (\lambda - 1)T_s.$$

$$T_s = \frac{P}{\lambda - 1}.$$

$$T_t = \frac{\lambda P}{\lambda - 1}.$$

$$T_s + T_t = \left(\frac{\lambda + 1}{\lambda - 1}\right)P.$$

$$K = \frac{(T_t + T_s) \times R_2 \times R_3 \times a}{R_1 \times R_4 \times R_5}.$$

TABLE 78*d*

VALUES OF λ FOR HAND BRAKES

Angle of Contact	Ratio T_t to $T_s = \lambda$ $f = 20\%$	$f = 30\%$
100°	1.418	1.688
120°	1.520	1.874
140°	1.630	2.081
160°	1.748	2.311
180°	1.874	2.566
200°	2.010	2.850
220°	2.155	3.164
240°	2.311	3.514
270°	2.566	4.111
300°	2.850	4.811

Where an electric brake is used, it shall be set by a spring and released by a solenoid. The brake will always be set except when the span is to be opened, when it will be released. If it is needed during the operation, it will again be set by cutting current off of motor. It shall be so designed that no injury will result if released indefinitely. There shall be a shunt circuit controlling the solenoid, and it shall be so arranged that the brake cannot operate while the motor is drawing current. A mechanical release

shall be provided so that the brake can be released in case of emergency operation. A shunt release shall be provided to hold brake off at will of operator to allow spans to coast. The shunt release switch shall be placed on the controller within easy reach of the operator.

For all operations performed by motive power, automatic limit switches shall be used to cut off the current at each end of travel for the wedges, locks, and gates, and at such a point near each limit of movement of the span that it will come to rest without jar. The limit switches shall be so made that they will be capable of suitable adjustment. For span operation a spring switch normally open shall be provided that will shunt around the limit switches and allow the operator to bring the span to its fully open or closed position, if necessary, after either limit switch has opened circuit.

The open and closed positions of the wedges, locks, gates, and span shall be indicated to the operator by means of electric lamps attached to the switchboard. The lamps shall show clear for closed positions when the span is ready for traffic, and shall show red for open positions. Each signal must be sufficiently accurate to indicate that the succeeding operation may be safely performed.

In addition to the previously mentioned indicators, a mechanical indicator shall be placed in the operator's house so as to show the position of the span to the nearest foot at any time during its movement. The last two feet of the downward movement of the span shall be given to the nearest inch. This indicator shall be placed in such a position that the operator can readily see it while operating the span.

All wiring shall be double-braided, rubber-covered, copper wire of ample capacity to carry the currents required by the motors for maximum loads without injurious heating and to provide satisfactory operation. No wires shall be less than No. 12 B. & S. gauge. The wires shall be drawn without injuring them into loricated or equivalent conduits. These conduits shall have as few bends as possible, and shall be directly connected to all apparatus so as to provide a weatherproof housing for the wires. In case alternating current be employed, all the wires of all phases (both feed and return) shall be placed in one conduit. Grounds, when used, shall be so thoroughly made and arranged that no damage from the current to either the superstructure or the substructure can ever occur.

In draw-spans the supply cables may be brought in overhead, or under the river and up through the pier. In either case collector rings shall be provided to conduct the current to the bridge while in motion. These rings shall be protected from the weather. Steel armored subaqueous cables shall be used when the wires are placed under the river; and there shall be separate cables for the supply and the return currents. Each cable shall be composed of nineteen strands of tinned copper wire of not less than ninety-eight (98) per cent conductivity. The insulating wall shall be not less than five thirty-seconds ($\frac{5}{32}$) of an inch thick and shall

contain not less than thirty (30) per cent of pure Para rubber. There shall be one winding of tape, and a lead sheath, three thirty-seconds ($\frac{3}{32}$) of an inch thick, the lead containing three (3) per cent of tin; also a substantial jute and asphalt covering and an armor of galvanized steel wire of suitable size for the diameter of the cable. The cables shall show at sixty degrees Fahrenheit an insulating resistance of five hundred megohms per mile after five minutes' electrification. All feed wires shall be protected by a pole-switch fuse and lightning arrester mounted on a non-combustible and non-absorbent insulating base.

In lift spans, vertical trolley conductors shall be placed on the front faces of the towers and shall extend for such a height that the collectors attached to the ends of the lift span can take current for any position of the span.

The contactors for making or breaking the electric circuits to operate the indicator lights or similar connections shall be of substantial design and of a type that has been operated successfully under similar conditions. They shall be protected from the weather and be easily accessible for inspection and renewal. All circuits shall be so arranged as not to interfere with the track signal circuit.

Switches of the quick-break type and of approved design shall be provided for each supply wire and for all circuits. They shall be mounted on the switchboard in the operator's house. The switches shall be designed to carry a current of not more than nine hundred (900) amperes per square inch of cross-section. Any knife-switch shall have a capacity of not less than one hundred (100) amperes. Emergency switches shall be used as noted on page 1704. Automatic circuit-breakers shall be placed on the switchboard to protect each motor circuit from excessive currents. All other circuits shall be protected by enclosed fuses. A voltmeter and an ammeter of ample capacity and standard make shall be placed on the switchboard.

A switchboard of first-quality slate and proper design shall be placed in the operator's house. It shall be of ample size to carry without crowding all meters, switches, fuses, circuit-breakers, indicator-lights, etc., and shall be attached well above the floor to a substantial frame. All apparatus on the board shall be properly labelled as to its use.

Electric lights of sixteen (16) candle-power shall be placed in the house so as to provide ample light for the house and for the inspection of the machinery. Lights with weatherproof sockets shall be used on the outside, on the stairs and walks, and at other points where needed. All lights shall be controlled by suitable switches. A light shall be placed over each indicating instrument or so arranged as to illuminate its dial.

Channel and signal lights shall be provided for the guidance of boats, as required by the U. S. Government.

Track signals when required will be furnished and installed by the railroad company, which will also furnish and put in place all levers and

interlocking devices between the signal system and the bridge operating equipment.

A bell, or other suitable signal, controlled from the operator's house, shall be installed to warn traffic that the bridge is about to be opened.

In selecting the equipment it should always be ascertained whether or not any particular locality requires special signals for boats, etc.; as this is sometimes the case.

92. *Internal Combustion Motors*

If a gasoline engine or other internal combustion motor is used, it shall be of the most substantial construction, and capable of producing a torque, based on the rated horsepower of the motor, twenty-five (25) per cent in excess of the maximum torque required. It shall be capable of performing the operation in the time specified, and shall have a piston speed not to exceed six hundred (600) feet per minute. For important bridges an engine shall be installed for operating the span, and another for operating the locks, wedges, and gates, when these are mechanically operated. On bridges of less importance a single engine may be used for all operations, in which case proper provision must be made for shifting from one set of machinery to the other. Friction clutches shall be employed to apply the load gradually to the engine. For engines of the 4-cycle type, which rotate in one direction only, two friction clutches, arranged in duplex, must be used so as to make possible the operation of the machinery in both directions. For the 2-cycle type, one friction clutch will be sufficient. Engines of ten (10) horsepower and more shall be started by compressed air. Engines shall be either air-cooled or water-cooled, as best suits the case in hand, and all accessories necessary for their complete operation shall be provided. The gasoline tank shall be placed outside of the engine house. Indicators shall be provided to show the positions of the span, locks, and wedges. Brakes, signals, lights, etc., shall be provided as for electric operation.

MACHINERY EQUIPMENT

93. *General*

The machinery equipment shall include all parts on which the span moves, as well as all parts by which the motion is either imparted or controlled, together with all details necessary to support or hold such parts.

All machinery shall be of simple but substantial construction. It shall be designed so as to be easily erected and adjusted; and it shall maintain its alignment after it is finally placed and bolted in position. Every part of the equipment must be easily accessible for inspection, cleaning, oiling, tightening, etc.; and the whole of it shall be so arranged that any part can be readily removed for repairs or renewal.

94. *Materials*

For the various parts of the machinery equipment, the following materials shall be used; but when the material is not mentioned in the specifications or on the plans, its character shall be determined by the Engineer.

For all structural parts—medium steel.

For rivets and bolts—rivet steel.

For equalizer-bars—medium or forged steel.

For keys, cotters, pins, axles, shafts, trunnions, screws, worms, and piston rods—rolled or forged steel. Shafting pins and trunnions over four (4) inches in diameter shall be of forged steel. Shafting under four (4) inches in diameter may be of cold-rolled steel.

For levers, cranks, connecting-rods, and rope-sockets—forged or cast steel. Rope sockets shall be drop-forged unless too large for the manufacturer's dies. In such a case either special dies shall be made or cast-steel sockets employed.

For the top, boxing, and base of pivot-stands, and for rollers, track, rack, end and centre shoes, latch-castings, sheaves under thirteen and a half (13.5) feet diameter, rims and hubs for sheaves over thirteen and a half (13.5) feet diameter, guide and centring castings, toothed wheels, bearings, couplings, and brake-lever stands—cast steel. Pinions shall be made of forged steel unless they are too large for forgings, in which case they shall be made of cast steel.

For pivot discs, friction rollers, ball-bearings, footsteps of vertical shafts, and wherever desirable to reduce the bearing area, abrasion, or friction—hardened steel.

For rail lock castings—manganese steel.

For the centre discs of pivots and the linings of journal bearings of trunnions—phosphor bronze for heavy loads and slow speeds.

For linings of shaft and footstep bearings and other rotating or sliding surfaces, to prevent seizing—phosphor bronze for light loads and high speeds.

Babbitt metal may be used for light loads and low speeds.

For counter weight cables and operating cables—plow steel.

Cast iron may be used for unimportant parts, such as small shaft bearings, idlers, etc.

95. *Loads*

In designing both the supporting and the operating machinery, the loads used shall be taken the same as those for which the power equipment is figured.

96. *Unit Stresses*

The unit stresses for the operating machinery, under normal conditions, shall be as given in Table 78*e*; and those for the supporting ma-

chinery shall be fifty per cent greater. Stresses set up in the machinery when the brakes are applied may exceed the normal unit stresses by not more than fifty (50) per cent.

The normal unit stresses may be increased one hundred (100) per cent when the bridge is being held against the maximum wind loads specified, or when operating by hand power with as many men as it is possible to utilize, each exerting a horizontal force on the levers of one hundred and twenty-five (125) pounds.

TABLE 78e

NORMAL UNIT STRESSES FOR OPERATING MACHINERY

Material	Tension	Compression	Bending	Shear	Bearing
Rivet Steel	.....	....	.....	5,000	10,000
Structural Steel	10,000	$10{,}000 - 40\frac{l^*}{r}$	10,000	7,000	12,000
Forged Steel / Machinery Steel	12,000	$12{,}000 - 45\frac{l^*}{r}$	12,000	9,000	15,000
Cast Steel	8,000	$10{,}000 - 40\frac{l^*}{r}$	8,000	6,000	10,000

In equalizer bars the metal back of the pin shall be figured at 10,000 pounds per square inch, and the metal through the pin hole at 5,000 pounds per square inch.

For parts such as shafting, in which the stresses reverse rapidly, the unit stresses shall be taken as one-half (½) of the values given above; and for parts such as trunnions, in which the reversals take place more slowly, the unit stresses shall be taken at two-thirds (⅔) the normal values for supporting machinery.

The strength of cut gear teeth shall conform to the following formula, one tooth only being assumed to take the entire pressure,

$$W = spfy;$$

in which W = tooth pressure in pounds,

s = allowable intensity of working stress,

= 15,000 pounds for velocities under 120 feet per minute,

$$= 18{,}000\left(\frac{600}{600 + v}\right) \text{ for velocities over 120 feet per minute,}$$

v = velocity in feet per minute,

p = circular pitch in inches,

f = face of tooth in inches,

and y = factor depending on number of teeth. (Table 78f.)

* With $\frac{l}{r}$ = 25 and less, use 9,000 lbs. for structural and cast steel, and 11,000 lbs. for forged and machinery steel.

TABLE 78f

FACTOR OF STRENGTH y FOR GEARS WITH 20° INVOLUTE TEETH

No. of Teeth	y	No. of Teeth	y	No. of Teeth	y	No. of Teeth	y	No. of Teeth	y
12	.078	22	.105	32	.116	43	.126	85	.139
13	.083	23	.106	33	.117	45	.127	90	.140
14	.088	24	.107	34	.118	47	.128	95	.141
15	.092	25	.108	35	.119	49	.129	100	.142
16	.094	26	.109	36	.120	50	.130	110	.143
17	.096	27	.111	37	.121	55	.132	120	.144
18	.098	28	.112	38	.122	60	.134	140	.145
19	.100	29	.113	40	.123	65	.135	150	.146
20	.102	30	.114	41	.124	70	.137	300	.150
21	.104	31	.115	42	.125	80	.138	Rack	.154

The allowable stresses per square inch for bearing on rotating and sliding surfaces shall be as follows:

For Slow and Intermittent Speeds:

Pivots for swing bridges, hardened steel on phosphor bronze.................................. 3,000 lbs.
Journal bearings for trunnions of lift and bascule bridges, steel on phosphor bronze............... 1,500 lbs.
Wedges, cast steel on cast steel, cast iron, structural steel, or bronze................................ 500 lbs.
Screws transmitting motion, on projected area of thread.. 200 lbs.

For Ordinary Cases, Moderate Speeds:

Hardened steel on hardened steel................... 2,000 lbs.
Hardened steel on phosphor bronze................. 1,500 lbs.
Tool steel (not hardened) on phosphor bronze....... 900 lbs.
Machinery steel on bronze.......................... 600 lbs.
Machinery steel on Babbitt metal................... 400 lbs.
Structural steel on cast iron....................... 400 lbs.

In order to prevent heating and seizing at high speeds, the pressure on pivots or footstep bearings for vertical shafts and journals shall not exceed the following:

On pivots.................................. $p = \dfrac{80,000}{nd}$,

On journals.................................. $p = \dfrac{300,000}{nd}$;

where n = number of revolutions per minute,
d = diameter of journal or pivot in inches,
and p = pressure in pounds per square inch.

For crank pins and similar joints with alternating motion the above values may be doubled.

The allowable pressure in pounds per lineal inch of roller in motion shall be as follows:

For cast iron.................................. $p = 200d$,
For cast steel................................. $p = 400d$,
For machinery steel............................ $p = 500d$,
For untreated tool steel....................... $p = 800d$,
For hardened tool steel .... $p = 1{,}000d$,

where p = pressure in pounds per lineal inch of roller,
and d = diameter of roller in inches.

The preceding values are for rollers and bearing surfaces of the same material; for different materials the smaller value shall be used.

The allowable pressure on balls of hardened tool steel running on surfaces of the same material shall be as follows:

For balls running on flat surfaces................$p = 600d^2$,

For balls running in grooves of radius $\frac{2d}{3}$.......... $p = 1{,}200d^2$;

where p = permissible load in pounds per ball,
and d = diameter of ball in inches.

The preceding values for rollers and balls in motion shall be doubled for rollers and balls at rest.

The total stress in the operating ropes and the counterweight ropes shall consist of the direct and bending stresses. The direct stress shall equal the direct load on the rope. The bending stress shall be determined from the following formula,

$$K = \frac{Ea}{2.06\frac{R}{d} + c};$$

where K = bending stress in rope,
E = modulus of elasticity = 28,500,000,
a = metallic area of rope in sq. in.,
R = radius of sheave in inches measured to centre of rope,
d = diameter of wire in inches,
and c = constant = 15.45 for 6×19 rope.

For the counterweight ropes, the ratio of the elastic limit to the total stress (including bending) shall not be less than two (2), and the ratio of the ultimate to the direct not less than six (6).

For the operating ropes the direct load shall be taken as the total pull required to start the span. The ratio of the elastic limit to the total stress shall not be less than one and one-half (1½), and the ratio of the ultimate to the direct not less than five (5).

Tables 16*a* and 16*b* give the weight, areas, ultimate strengths, elastic limits, and bending stresses of 6×19 wire ropes from ¼″ to 3″ in diameter.

Rope sockets shall have an intensity of tensile stress not to exceed 65,000 pounds when the attached ropes are stressed up to their ultimate

strength. Tables 16*c* and 16*d* give the dimensions for open and closed sockets, respectively, for different sized ropes.

Designing and Detailing for Machinery of Movable Spans

97. *Track, Rack, Rollers, and Centre Casting for Rim-Bearing Draw-spans*

The tracks and rollers for rim-bearing swing spans shall be so designed as to provide a support for the swing span that will maintain exact alignment and will distribute the loads properly to the masonry. The entire dead load shall be carried by the rollers while the span is swinging, and the entire dead and live loads on the pivot pier shall be carried thereby when the span is closed.

The upper track shall be made of segments of sufficient thickness to distribute the load properly between the rollers and the drum. The top face of this track shall be planed smooth so as to form close contact with the bottom flange of the drum, and the lower face shall be planed conical so as to fit closely to the conical rollers. All joints between segments are to be planed smooth and to such bevel as to ensure perfect contact with each other. These track segments are to be riveted or bolted to the bottom flanges of the drum with fifteen-sixteenths ($^{15}/_{16}$) inch rivets or bolts, placed opposite, and spaced not to exceed fifteen (15) inches between centres. The heads of these bolts or rivets are to be countersunk in the track on the side next to the rollers. No rust cement or any other composition is to be used between the track and the drum.

The lower track is to be made strong enough to distribute the load from the rollers uniformly over the masonry. Its top is to be planed to a true conical surface to fit closely to the conical rollers. The bending moment on the lower track is to be found by the formula,

$$M = \frac{1}{12} Wl,$$

where M = greatest bending moment on lower track, W = total load on one roller, and l = distance from centre to centre of adjacent rollers, measured on the centre line of the track. The lower track shall be made in segments from six (6) to eight (8) feet in length. All abutting ends of lower-track segments are to be planed smooth, are to have close contact throughout, and are to be bolted together at each joint by not less than two bolts passing through holes in lugs cast thereon. These bolts are to be at least fifteen-sixteenths ($^{15}/_{16}$) of an inch in diameter. In no case shall the upper track be less than two and one-quarter ($2\frac{1}{4}$) inches thick for railway spans or one and three-quarters ($1\frac{3}{4}$) inches for highway spans, or the lower track less than two and one-half ($2\frac{1}{2}$) inches thick for railway spans or two (2) inches for highway spans, measuring on the central cylindrical surface of the drum.

The lower track shall be anchored to the top of the pivot-pier with bolts not less than one (1) inch in diameter, nor less than fifteen (15)

inches long, set in place with Portland-cement grouting. These bolts are to be made of soft steel, with hexagonal nuts at top, and with split ends and wedges at the bottom. They are to be placed in pairs opposite on the inside and outside of the track, and are to be spaced not to exceed eighteen (18) inches between centres.

The rollers shall be of cast steel, and are to be made solid, excepting only the centre hole and four or more radial holes that are left in the casting for the double purpose of reducing the weight and facilitating a rapid and uniform cooling, the said holes varying in size and number with the diameter of the roller. In no case shall the rollers be less than twelve (12) inches in diameter and seven (7) inches on face for railway spans, nor less than ten (10) inches in diameter and six (6) inches on face for highway spans. All rollers, and the faces of the upper and lower tracks which are in contact with the rollers, are to be turned smooth to the forms of right frustums of cones the vertices of which intersect at the centre of the drum, so that the rollers will have perfect contact with the tracks throughout their travel around the entire circumference. A bearing is to be turned in the centre of each roller for the radial rod; and oil-holes are to be provided on both the interior and the exterior ends of the rollers, so that these bearings can be kept well lubricated. Turned bosses must be provided on both the inner and the outer ends of the roller, to bear against the collars and the friction-washers. The outer ends of the radial rods are to pass through the rollers, and the inner ends are to attach to a circular plate fitting closely around the centre casting. These radial rods are to be provided with nuts for adjusting the position of the rollers. Only square sections are to be used for the rods, and each must contain at least one square inch of section. The end of the rod passing through the roller must be upset so as to provide a turned shaft for the latter at least one and one-half ($1\frac{1}{2}$) inches in diameter. The outer ends of these rods are to pass through a stiff steel ring of rolled or built channel section, which is to serve as a spacer for the rollers. These channels must be made wide, but not deep, and their section is to be commensurate with the size of the turntable. They are to be held away from the rollers by friction-washers on the rods. On the inside of the rollers collars are to be forged and turned on the radial rods to hold the said rollers in exact position on same. An inner spacing ring, of size commensurate with the magnitude of the drum, is to be attached to the radial rods. For small bridges this ring may consist of a single angle with a pair of small lug angles riveted thereto for each radial rod, placed as near the inner ends of the rollers as practicable. For large drums the arrangement should be somewhat modified by making the inner ring in the form of a small curved plate-girder lying in a horizontal plane and rigidly braced to the centre casting by radial struts that are riveted at the outer ends to the curved girder and at the inner ends to a large circular plate which fits snugly around a turned bearing on the centre casting.

With this detail the radial rods are to be shortened, and their inner ends are to be attached to the circular girder instead of to a plate on the centre casting. These rods should be not less than two and a half (2½) inches square, and the journals should not be less than three (3) inches in diameter. There must be nuts at both ends of the bars so as to move the rollers radially to the drum; and the inner ends of the bars are to be so attached to the circular plate as to permit of the correction of any slight variation of their axes from a truly radial direction.

The centre casting must be made strong and heavy, and must be effectively anchored to the top of pier by eight (8) or more anchor-bolts not less than one and one-fourth (1¼) inches in diameter and not less than three (3) feet long for railway structures nor less than one and one-eighth (1⅛) inches in diameter and two and one-half (2½) feet long for highway structures. These bolts are to be made of soft steel, with hexagonal nuts at top, and with split ends and wedges at bottom. The least allowable thickness of metal for this casting shall be one and one-half (1½) inches for railway spans and one (1) inch for highway spans. The base shall be true and level; and an even bearing shall be secured by bedding in neat Portland-cement mortar. For heavy draws this centre casting is to be set well into the masonry, then grouted in place. All bearings for plates which rotate on this casting are to be turned smooth and provided with suitable oil-grooves, so they may be easily oiled. A cap-plate for holding down the top connection-plate for the radial struts is to be attached to the top of the centre casting.

The rack for turning the span is to be made in short sections, not over four feet long, so that in case of breakage only a small portion need be replaced. These rack segments are to be bolted to the lower track with tap-bolts not less than fifteen-sixteenths ($^{15}/_{16}$) of an inch in diameter, and spaced not to exceed fifteen (15) inches between centres. In any case there must be enough of them in any one segment of the track to resist, with a good margin for contingencies, the entire shear, and also the stresses due to the rotating moment caused by the tooth pressure of the pinion or pinions that engage with the said segment. The least allowable thickness of metal in the rack shall be one and one-eighth (1⅛) inches. The ends of the rack segments are to be planed so as to secure close contact, and the abutting ends are to be bolted together with turned bolts at least seven-eighths (⅞) of an inch in diameter. The bottom of the rack and that portion of the lower track upon which the rack bears are to be planed smooth. The width of the base of the rack shall be at least two-thirds (⅔) of its height; and ribs bracing the vertical portion to the base shall be provided at distances not exceeding eighteen (18) inches. Drainage holes about one inch in diameter, spaced not more than two (2) feet between centres, shall be bored in the lower-track segments, starting just back of the rack and leading to the outside of the track.

98. *Pivot, Track, Rack, and Rollers for Centre Bearing Swing Spans*

In centre bearing swings, the centre pivot shall carry the entire dead load of the span both when swinging and when closed. This pivot shall be composed of a cast steel base supporting a disc-bearing, roller-bearing or ball-bearing that carries the top casting on which the structural work is directly supported. The disc-bearing has given the best results and shall generally be used. The phosphor-bronze disc shall be made convex on both faces and shall lie between two hardened steel discs which have curved surfaces bearing on the centre disc, but of slightly larger radius. The other surfaces of these discs shall be plane and shall bear on the upper and the lower castings and be doweled to them so as to insure that the sliding shall take place on the bronze disc. An oil-tight, cast-steel box shall be placed around these discs and attached to the base casting. This box shall be of substantial construction with a total clearance of one-thirty-second ($1/32$) of an inch between the discs and the box. It shall be made in sections and bolted together so as to permit removal for the inspection and the renewal of the centre disc whenever necessary. Semi-circular vertical oil grooves of $1/2$ inch radius shall be placed around the inside of the boxing and connected with an oil space around the top. Oil holes feeding into this oil space shall be provided in the top casting. The latter shall completely protect this oil space from dust, etc. Oil grooves of three-eighths ($3/8$) inch radius shall be cut in diametral lines across both faces of the centre disc. A hole one (1) inch in diameter shall be drilled in all three discs at the centre. This hole shall feed into oil grooves cut on diametral lines across the top face of the base casting. Holes shall be drilled into this casting at the ends of these grooves and tapped for drain pipes. The sliding contact faces at the discs shall be polished, whereas all other surfaces shall be merely finished. The base casting shall be well anchored to the pier by not less than eight bolts, each one and one-half ($1\frac{1}{2}$) inches in diameter and three (3) feet long.

The circular track for steadying the span when in motion and the operating rack are to be cast separately in segments, and bolted together effectively so that broken rack segments may be easily replaced. The previous specifications are to govern the design of these tracks and racks, excepting that the track may be as narrow as seven (7) inches. Generally there are to be six (6) or eight (8) trailing wheels not less than eighteen (18) inches in diameter and six (6) inches face, the axles being not less than three (3) inches in diameter. The wheels are to be set in a radial position so as to run truly on the track; and they are to be securely fastened in correct position. Provision shall be made for adjusting the rollers so that they will just clear the track when the span is swinging. The rollers and support shall be designed to take the reaction from a fifteen (15) pound wind tending to overturn the span about the pivot.

99. *Centre Wedges for Centre-Bearing Swing Spans*

When the span is closed, the live load shall be carried on the centre wedges. They shall not be designed to lift the trusses but merely to provide a good, firm bearing. For this reason a flat bevel of about one (1) to ten (10) is desirable. Two wedges, one at each side of the pivot near the trusses, will generally suffice. Proper provision shall be made for adjustment. The wedge shall bear on an upper casting provided with guides engaging lips on the wedge. These guides and lips shall be so arranged that the wedge will be supported by the upper casting during the swinging of the span. The wedge shall bear on a base casting substantially bolted to the pier.

100. *End Lifts for Swing Spans*

All swing spans shall have an arrangement to lift the ends thereof so as to make the span continuous over the centre supports for all conditions of loading. Wedges, toggle-joints, eccentrics, and rollers with links may be used for this arrangement. Whatever detail is employed, it shall be able to lift the ends to the desired elevation and form a solid, substantial support as for fixed spans. In figuring the amount of movement to be provided for, the possibility of the top chord's having a temperature 30 degrees F. greater than that of the bottom chord must be duly considered.

Wedges give very satisfactory supports. When used they shall move in the line of the trusses and bear directly under the same in the line of the end floor-beams. The upper surface of the wedge shall be beveled about one (1) to five (5), and shall engage guides in the upper bearing casting, which is directly attached to the truss so that the wedge will be supported by the span when swinging. The lower surface of the wedge shall be horizontal, and shall bear on the base casting that is bolted directly to the pier. The base casting shall have guides to engage the wedge, but these guides must not interfere with the span while swinging. All surfaces in contact are to be finished and polished.

Where roller bearings are employed, rollers are to be provided beneath the end-pins of the trusses and attached to the span by means of links which are operated by struts attached to the pins passing through the rollers. The axes of the rollers shall be parallel to the trusses and shall be moved during operation in a transverse direction. The rollers must be bored so as to provide a fairly close fit over the pins at the bottom of the links. Both the pins and the insides of the rollers must be finished very smooth; and provision must be made for oiling the bearings between them. No roller shall be less than six (6) inches in diameter, and the pins inside of them shall not be less than three and one-half (3½) inches. In all draw bridges where, on account of infrequent operation combined with great changes of temperature, there is a tendency to drag

the rollers on their bearings, the links and all details must be made strong enough to overcome the friction and thus allow the ends to adjust themselves, or else special longitudinal roller bearings must be provided. The bearings for the rollers shall be cupped one-eighth (1/8) inch or more in depth so as to provide ample bearing area; and shoulders must be provided on the shoes to furnish a side bearing for the rollers when lowered into place. Each shoulder must be machined so as to fit the roller exactly when in its final position with the end of span fully raised. The height of these shoulders shall be about one-third (1/3) of the diameter of the roller, but never enough to interfere with the span while swinging. The shoes at each end of the span shall be connected by adjustable rods not less than one and one-half (1½) inches in diameter, and strong enough to take up the entire thrust from the operating struts.

A toggle arrangement may be used, the upper end thereof being fastened to the truss by a pin, and the lower end connected by another pin to a shoe moving in vertical guides. The reaction at each corner is carried upward through the toggle links to the upper pin and into the truss. The operating arm is to be attached at the centre of the toggle and operated in the plane of the truss. In connection with this apparatus a nest of segmental rollers with transverse axes may be used at the ends for cases in which the spans open very infrequently and when temperature changes are great, so as to minimize the effect of the expansion and contraction of the steelwork. These rollers shall be provided with a device for throwing them into correct vertical positions when the ends are free. Ample provision shall be made for adjusting the bases.

For bob-tailed draw spans it is usually best to place the end lifts at the end of the long arm only.

Proper provision for adjustment must be made in all cases.

101. *Latch for Swing Spans*

To bring the draw span to rest and proper position when closing, an automatic latch of the Pencoyd type shall be used. One shall be placed at the centre of each end floor-beam.

102. *Suspending Cables for Vertical Lift Spans*

In vertical lift bridges the movable span shall be balanced by a counterweight at each end, connected to the span by wire ropes passing over sheaves at the tops of the towers.

These counterweight ropes shall be of plow steel, and shall consist of six (6) strands of nineteen (19) wires each, laid around a hemp centre. They shall be of approved make and shall conform to the values given in Table 16*a* as to their elastic limits and ultimate strengths. The ropes shall be designed as noted under "Unit Stresses." They shall have as small side leads as possible, in no case exceeding one (1) in forty (40).

The stretch in the ropes due to direct load shall be figured by the formula,

$$S = \frac{LD}{Ea};$$

where S = Stretch in inches,
L = Calculated length of rope in inches,
D = Direct stress in pounds,
E = Modulus of elasticity for stretch,
= 17,000,000,
and a = Metallic area of rope in inches.

The manufactured length shall be the calculated length minus the stretch in the ropes. The manufactured lengths of the ropes shall not vary from the dimensions indicated on the drawings by greater amounts than those given in Table 78*g*.

TABLE 78*g*

ALLOWABLE VARIATIONS IN FABRICATED LENGTHS OF WIRE ROPES

Manufactured Length	Variations (+ or −)
0-100′	1/4″
100-200′	3/8″
200-300′	1/2″
300 and upward	3/4″

103. *Rope Sockets*

Rope sockets shall be either open or closed as required. They shall be of the standard dimensions shown in Tables 16*c* and 16*d*.

104. *Equalizers*

The counterweight ropes shall, as a rule, be connected directly to the steelwork on the lift-span side, but on the counterweight side they shall be attached to equalizers, which, in turn, are attached to the counterweight. Each equalizer bar shall be made with the centre pin below the end pins. This distance will depend on the layout and design of the bars, because no vertical links shall be used between the bars except to change the direction, as noted below. The layout of the equalizers will depend on the type of counterweight used, whether sectional or solid. In the sectional type four ropes shall generally be attached to each section, and the equalizer bars shall be placed parallel to the axis of the bridge. In the solid counterweight, the upper equalizer bars, to each of which two ropes are attached, shall, as a rule, be placed transversely to the axis of the bridge. They shall be attached to the lower equalizer bars,

which run parallel to the axis of the bridge, by criss-cross links. On the span side, open sockets shall generally be used; and on the counterweight side, closed sockets. All pins connecting the various equalizer bars shall have a head one-quarter (¼) inch thick on one end and a split cotter on the other. The pin connecting the bottom bars to the counterweight hanger shall have the ends threaded for Lomas nuts. Provision shall be made for removing any pin connecting the sockets to the bars or lift span in case it becomes necessary to replace a rope, and the equalizers shall be so designed that a rope can be replaced without supporting the counterweight. All pins in the upper equalizer bars shall be of the same size, viz., that used for the sockets. The clearance between any two parts shall be greater than one-half (½) inch, which amount shall be considered no clearance.

105. *Tower Sheaves*

Tower sheaves having a pitch diameter of thirteen and a half (13.5) feet and under shall be made of cast steel, and those of greater diameter shall be built up of structural steel with a cast-steel rim and hub. The pitch diameter of the sheave shall not be less than sixty (60) times the diameter of the rope. The ropes shall be spaced on the sheave a distance apart equal to the diameter of the rope plus one-eighth (⅛) of an inch. The grooves in the sheaves shall be made to fit the ropes. The metal between the grooves shall be rounded off with the top of each ridge from one-eighth (⅛) to one-quarter (¼) inch below the pitch line. The distance from out to out of rim shall be equal to the distance between the centres of the end ropes plus two (2) diameters of the rope. The outside of the rim shall project one-half (½) the diameter of one rope above the pitch line. The inner face of this lip shall make an angle of fifteen (15) degrees with the vertical.

Tower sheaves shall have not less than eight (8) spokes, which may be tee, cross, elliptical, or H in section. Each rib shall have sufficient area to carry the load on the sheave, distributed over a length equal to the distance from centre to centre of spokes, and to resist the bending due to the friction on the journals. In all cases where the spoke consists of two ribs, one at each side of the sheave, the rim must be properly supported between these sections for its full width. It must also be properly supported longitudinally between the spokes. In cast sheaves the hub diameter shall be one and eight-tenths (1.8) times the diameter of the shaft, but shall not exceed the said diameter by more than ten (10) inches. The hub shall have a greater length than the distance from out to out of rim. It shall be made to bear on the shaft only as required on each side under the spokes.

Structural sheaves shall be built up of plates conforming to the outline of the said sheaves, one or more being used at each side, supporting a segmental cast-steel rim and connected by cross diaphragms. The

plates should have openings in them between these diaphragms. These plates shall bear on the shaft and shall be reinforced for bearing by additional plates and the hub castings. The latter shall consist of circular discs on the outside and a spool between the webs. The inside casting shall extend across the journal for the full width between plates, but shall bear on the journal only the required amount at each side. The webs, reinforcing plates, and castings shall all be riveted up and then bored for the shaft.

The rim sections shall have side flanges for connection to the side plates of the sheave and cross ribs at each diaphragm. These cross ribs shall be riveted or bolted to the diaphragms. The entire load from the ropes shall be delivered from the rim to the structural part of the sheave by rivets or turned bolts, no reliance being placed on any bearing that may exist. All abutting surfaces shall be finished for perfect contact. The grooves in the rim shall not be turned until the segments have been assembled and riveted or bolted to the structural work. Drain holes shall be provided in all sheaves where water is likely to collect.

106. *Tower-Sheave Shaft*

The shaft for the sheave shall be designed for the greatest bending and shearing stresses that may come on it. The diameters of the portions in contact with the sheave shall be greater than that of any other part of the shaft, the diameter at one bearing point, and the corresponding bore in hub metal, being not less than one-sixteenth ($1/16$) of an inch larger than that at the other. The sheave shall be pressed on the shaft, and not less than three keys shall be used between the sheave and shaft. They shall be designed for a shearing force equal to twenty (20) per cent of the total load on the sheave. The bearing surface of each journal shall be of a length not less than the diameter thereof plus two inches. It shall be highly polished. Where the cross-section of the shaft changes, fillets shall be used.

Beyond the bearings the ends of the shaft shall be shouldered and likewise filleted. When the journal diameter exceeds eight (8) inches, a hole, having a diameter equal to one-fourth ($1/4$) that of the journals, shall be bored through the shaft for its entire length. Oil grooves one-quarter ($1/4$) inch wide and one-half ($1/2$) inch deep shall be cut in the journals parallel to the axis of the shaft. They shall be machine-cut with the upper edges rounded off. Provision must be made for cleaning the grooves. A large well shall be bored in each end of the shaft and connected with the oil grooves. In case the centre of the shaft is bored out, the inner ends of the wells shall be screw plugged. The outer ends shall also be screw plugged and tapped for marine-type, screw-feed grease-cups of not less than one pint capacity.

107. *Tower-Sheave Journal Bearings*

The journal bearings shall consist of two parts, the base and the cap. The base shall be bolted to the steelwork with four turned bolts. The holes in the structural work shall be drilled to an iron templet made from the holes in the casting. The cap shall be bolted to the base with four bolts. Finished bosses shall be provided on the castings for the nuts and heads of the bolts. The joints between the cap and the base shall be finished, and shims shall be furnished for adjustment. The base only shall be provided with a bushing. It shall be made of special bronze for high bearing pressure and low speed. Its thickness shall not be less than one-twelfth ($1/12$) of the diameter of the shaft with a minimum of five-sixteenths ($5/16$) inches. All bushings shall be securely held by the bases. They shall be scraped to fit their journals and match-marked for field erection. When considered advisable to do so, the bronzes shall be designed so that they may be removed and renewed, if necessary. The caps shall be provided with eye-bolts for handling.

108. *Sheave Hoods*

The sheaves shall be protected by hoods made of structural steel and attached to the towers. These hoods shall be formed of top and side plates of number sixteen (16) gauge, the former bent to a radius 2″ greater than the extreme radius of the sheave and riveted to $1\frac{1}{2}'' \times 1\frac{1}{2}'' \times \frac{3}{16}''$ angles. The side plates shall be six (6) inches wide, sufficient to protect the ropes from the weather.

109. *Guides for Vertical Lift Spans*

The lift span shall be held in alignment by steel guides attached to the four corners at the top and the four at the bottom of the span, engaging tracks riveted to the front tower columns. These guides shall be of either the roller or the sliding type. They shall be properly attached to the span so as adequately to provide for all loads that may come on them. They shall be designed for a fifteen (15) pound wind load, except as hereinafter provided. All guides shall have unlimited freedom of movement longitudinally, excepting the bottom chord guides at one end of the span, which shall be arranged so as to fix that end. There shall be ample clearances between the guides and the track. Provision must be made for the field adjustment of the relative positions of guides and tracks. Where the guide castings also adjust the position of the span either longitudinally or both longitudinally and transversely, taking the place of centring castings, they shall be designed for a thirty (30) pound wind pressure, also for the thrust from braked trains in the case of railroad bridges.

110. *Centring Castings*

The lift span shall, as a rule, be brought to exact position when closed by means of centring castings, generally attached to the four lower corners of the span, which engage castings attached to the towers. The castings shall be arranged so as to hold one end of the span fixed and allow longitudinal movement of the other end. The castings shall be designed for a thirty (30) pound wind load on the span, and in addition those at the fixed end must take the traction load in case of railroad bridges. Where electric or steam railroads pass over the structure, the span shall be centred the height of the rail plus one (1) inch above its lowest position. The centring faces of the engaging and engaged castings shall have bevels not to exceed one (1) in twelve (12). Proper provision shall be made for adjusting the centring castings in the field.

In highway bridges the centring may be taken care of by means of the guide castings by flaring the track at the lower end. In low lifts the clearance in the guides may be made so small that further provision will be unnecessary for centring the span. But where the lift is great and when a large transverse clearance has to be provided in the guides on account of possible irregularities in the guide tracks or because of the wide spacing of trusses, causing excessive changes in length of lift-span end floor-beams, the final transverse centring shall be done by special centring devices. These shall be attached to the end floor-beams at the centre, and shall be designed for the transverse wind only. Especially is this necessary where a street railway passes over the bridge. Where a wide spacing of trusses is used in railroad bridges, the same arrangement must be resorted to. The traction load in such a case will have to be taken care of by the centring casting or by the guide castings.

The clearance in the centring castings shall be such that the guide and rail castings will not tend to centre the span. One-eighth (1/8) inch total clearance each way will suffice.

Centring castings shall also be provided on bascule spans at the swinging end.

111. *Rail Locks*

At each end of all movable spans provision shall be made for making the track continuous. Loose rails shall not be used. In lift bridges manganese steel rail castings may be bolted to the rails on the lift span and project over the openings on to bearings, engaging the rails and the supporting castings on the fixed spans. A portion of the head and base of the rail shall be planed off on the outside so that the casting can be fitted to the web. The casting at its outer edge shall be one-eighth (1/8) of an inch higher than the rails over the opening, the top surface having a bevel of one (1) in twenty (20) toward the inside. The ends of the casting

shall be depressed below the top of the rail one-quarter (¼) inch and the casting shall have a gradual rise from this point toward the centre. The same arrangement may be used on the swinging end of bascule spans and on the fixed span at the opposite end. A similar arrangement may also be used on swing spans, but the casting shall be pivoted some distance back from the opening so that it can be raised over the rails on the fixed spans and thus prevent interference in swinging. In highway spans the expansion plates shall be lifted by the same operation.

In railway spans the openings between the movable and the fixed spans shall, preferably, be bridged by tongue castings operated from the movable span. These shall engage the rails and tongue guides on the fixed spans.

112. *Span Locks and Buffers*

An arrangement for locking the span in its closed position shall be used for all movable spans. It shall be of substantial and efficient design.

Hydraulic or other buffers of approved type shall, preferably, be used for bringing both lift and bascule spans to rest without shock, although, as some engineers consider it legitimate to rely upon the machinery to accomplish this result, it may not be improper to omit the said buffers.

113. *Rack Pinions for Swing Spans*

Swing spans shall be turned by pinions engaging the rack, the necessary gearing being introduced between the pinion and motive power to open and close the span in the required time. Where two pinions are employed, they shall be placed diametrically opposite, and the tooth pressures shall be equalized by differential gearing in the main drive machinery. Where four pinions are used, they shall be placed diametrically opposite in pairs, and the two pinions of each pair shall be placed as close together as practicable and equalized by gearing. Each set of pinions shall be operated by a separate motor. The two motors shall be operated by the same controller, thus equalizing the action of the two sets of pinions.

114. *End Lift Machinery for Swing Spans*

The end lifting and locking machinery shall have its principal reduction at the ends of the span so that the line shaft can operate at a high speed and light torque. The centre wedges in centre bearing spans shall be operated at the same time the end lifts are operated. The entire mechanism shall be so adjusted that the centre wedges will come to a firm bearing at the same time that the ends of the span have been lifted the required amount.

115. *Operating Ropes for Lift Span*

The lift span shall be raised and lowered by means of operating ropes at each side of the span attached to drums at the centre and passing over deflecting sheaves at each end of the span to the top and bottom of the towers. Either one or two ropes for raising and the same for lowering shall be used at each corner, the number depending on the force required to move the span. These ropes shall be fastened to the drums with forged-steel clips. A take-up device attached to the towers shall be provided at the ends of the operating ropes to take up any slack therein. This mechanism shall consist of a turnbuckle, bolt and nut, or drum. If a drum is used, it shall be operated by a worm gear with the worm fitted for a hand-turning lever. The operating ropes shall never be less than three-quarters (¾) of an inch in diameter. They shall be of six (6) strands of nineteen (19) wires each, and shall conform in general to the requirements given for counterweight ropes.

116. *Operating Drums for Lift Spans*

There shall be either two or four operating drums located at the sides of the span at the centre thereof. For small spans two drums shall be used, one at each side; and they shall be grooved so as to take the ropes from both ends of the span. For larger spans four drums shall be employed, two at each side. In girder spans where four drums are used, one drum shall be placed at each corner of the span. Each drum shall be grooved to take the ropes from the corresponding end. The diameter of the drum from centre to centre of ropes shall be not less than forty (40) times the diameter of the operating rope, except where a rope less than three-quarters (¾) of an inch in diameter will figure for direct load and bending or where the ratio of the ultimate strength to direct bending is greater than six (6), in which case the drum diameter may be thirty (30) times the diameter of the rope. The distance from centre to centre of ropes shall equal the diameter of the rope plus one-sixteenth ($^1/_{16}$) inch. Care shall be taken to see that the holes in the drums through which the ropes pass are large enough to pass both the rope and the mousing. The grooves in the drum shall be finished to fit the ropes, and the metal between the ropes shall be rounded off as in the tower sheaves. The number of grooves shall be such that when either the up-haul or down-haul ropes are payed off to the extent of the travel of the lift span, these ropes will still have one and one-half (1½) turns wrapped on the drum. All parts of the drum shall be of ample strength to withstand the pull in the operating ropes. The hub shall extend about one-half (½) inch beyond the outside of the drum at each end.

117. *Deflecting Sheaves for Operating Ropes*

The deflecting sheaves at the ends of the span shall have the same diameter as the operating drums. The grooves shall be turned to fit the ropes, which shall be spaced from centre to centre a distance equal to the diameter of one rope plus one-quarter (¼) inch when two ropes are used. The outside flanges of the grooves shall extend about one and one-half diameters of the rope above its centre. The inner faces of these flanges shall make an angle of fifteen (15) degrees with the vertical; and the distance from out to out of rim shall be such as to give a proper thickness of metal at the edges. The rims and grooves shall be finished.

The deflecting sheave shall have not fewer than eight spokes, which may be tee, cross, or elliptical in section. The sheave shall turn on a fixed shaft supported by the structural work. The hub shall be bronze-bushed and tapped for marine-type, screw-feed grease-cup with pipe extension screwed into the bushing. Proper provision shall be made in the bushing for lubrication. A small idler sheave shall be placed below the deflecting sheave and toward the centre of the span from it, to carry the up-haul rope and prevent it from leaving the deflecting sheave when slack.

118. *Supports for Operating Ropes*

Where necessary to support the operating ropes between the operating drum and the deflecting sheave, or to keep the ropes off of the steelwork, gum-wood rollers shall be used. They shall be of such diameter—never less than six (6) inches—that the rollers will turn, preventing the ropes from dragging on and cutting grooves in them. They shall be placed at as many points as necessary to support the ropes; and in trusses with curved top chords they shall be located at each panel-point, and at intermediate points, if needed.

119. *Operating Machinery in General*

The machinery between the motors and the operating drum or rack pinion shall be as compact as possible, and shall have as few reductions as good designing will permit. The layout shall be such as to give a good, economical design with as few parts as possible.

120. *Operating Machinery for Swing Spans*

In a swing span the main machinery shall be placed at the centre of the span, either below the floor, in case there is sufficient room for such an arrangement, or up between the trusses, or on the top of the latter, if the headway be restricted.

121. *Operating Machinery for Lift Spans*

In a lift span the machinery shall likewise be placed at the centre of the span either on top of the trusses or between them. Where four drums are used, one reduction shall be installed at the drums. A single shaft shall extend out from the main machinery in the house with a pinion at the end engaging duplicate gears fastened to the drums.

122. *Gears*

All gears shall have twenty (20) degrees, involute, machine-cut teeth. They shall be designed by the rules given under "Unit Stresses," page 1710. The sides shall be faced and the pitch lines scribed on both sides. The face width of a gear shall be from two (2) to three (3) times the circular pitch. The thickness of the rim shall not be less than four-tenths ($^4/_{10}$) of the circular pitch plus one-quarter ($\frac{1}{4}$) inch. All gears employed between the motive power and the operating drums or rack shall have at least six (6) spokes or else solid webs; those employed to drive limit switches, mechanical indicators, etc., may have four (4) spokes. The spokes may be elliptical, tee, or cross in section. They shall be figured as cantilever beams free at the pitch line and fixed at the hubs, each spoke taking its direct proportion of the load on the tooth. The hub diameter shall be one and eight-tenths (1.8) times the diameter of the shaft, but not to exceed the said diameter plus ten (10) inches. The hubs shall be faced and shall have a length greater than the face of the gear.

Bevel gears shall be avoided as far as possible.

123. *Worm Gears*

Worm gears may be used for minor operations. The worm shall be below the gear and shall run in oil. It shall be made of forged or rolled steel, and the gear shall be of bronze. The end of the worm shall bear on a bronze collar, and the shaft of the gear shall rotate in bronze bushings. The gear shall have not less than twenty-eight (28) teeth. The threads on worms shall be cut, and the gear teeth must fit the worm accurately. A standard worm set shall preferably be used.

124. *Pinions*

Pinions, as a rule, shall have not less than seventeen (17) teeth. Under certain conditions, as in the pinion engaging the rack in draw spans, the use of fifteen (15) teeth may be allowed, in which case stub teeth will probably have to be adopted to give swinging clearance. The face width of pinion shall be from two and one-half ($2\frac{1}{2}$) to four (4) times the circular pitch and always greater than that of the gear it engages. The

hubs shall be as specified for gears. Generally the reduction ratio of the gear to the pinion shall not exceed four (4) or four and one-half ($4\frac{1}{2}$).

125. *Shafts*

All shafting shall be designed for an equivalent moment,

$$M = \tfrac{1}{2} M_1 + \tfrac{1}{2} \sqrt{M_1^2 + M_2^2};$$

Where M_1 = Bending moment on the shaft,
and M_2 = Twisting moment on the same.

A proper reduction shall be made for the keyways in determining the diameter of the shaft. The minimum diameter of any shaft shall be two and one-half ($2\frac{1}{2}$) inches. The unsupported length of shafts carrying their own weight shall not exceed

$$l = 80 \sqrt[3]{d^2};$$

and for shafts carrying gears, etc.

$$l = 50 \sqrt[3]{d^2};$$

where l = length of shaft between bearings in inches, and d = diameter of shaft in inches. All shaft journals shall be polished.

126. *Keys*

Keys shall be designed so as to develop the full torque on the shaft. The width of the key shall generally be about one-fourth ($\frac{1}{4}$) of the diameter of the shaft, and the depth shall be about equal to the width or slightly less. In all cases, however, the keys shall be designed for shearing and bearing within the unit stresses specified. The length of the keys shall not be less than the length of the hub. Taper keys shall not be used except in special cases; and all keys shall be fitted to the keyways so as to have perfect bearing on all faces. Set screws shall be used wherever there is a possibility of sliding on the keys. They shall be made safe by having the heads protected in countersunk holes in the hubs. Where it becomes necessary to remove keys, the keyway shall be extended so that it will be possible to drift the key from the shaft. Where more than one key is employed they shall be placed one hundred and twenty (120) degrees apart. Keys shall be placed only beneath the spokes.

127. *Bearings*

Bearings shall be provided for the shafting as near the points of loading as possible. As far as it is practicable to do so, the machinery shall be arranged in a compact unit; and a single bearing frame shall be used

for all the shafts in the unit. The bearings, however, shall be so laid out that any gear can be removed without disturbing the other gears. Where bevel gears are employed, the bearings for each set shall be in one piece. Single bearings shall be provided at all points where it is necessary to support the shaft in accordance with the rules given for unsupported length. All bearings shall be split bearings with finished joints; and shims shall be provided between the cap and the base for adjustment. The caps for large bearings shall be bolted to the bases with four turned bolts, and for small bearings with two such bolts. Finished bosses shall be provided for the bearing of all nuts and heads of bolts. The bolt holes shall be drilled. In large bearings the caps shall be provided with eyebolts for handling. Bearings shall be bolted to the steelwork with turned bolts having a driving fit. The bearings shall be assembled on the steelwork at the shop and the holes drilled while they are thus assembled, where it is possible to do so. When this cannot be done, they shall be drilled to an iron templet in both the casting and the steelwork.

128. *Bushings*

All bearings, unless specially noted otherwise, shall have bronze bushings, the thickness of which shall be one-twelfth ($^1/_{12}$) of the diameter of the journal. They shall be split at the juncture of the cap and the base castings, and shall be held against turning by the shims between these. The bushings shall be grooved for lubrication, and the grooves shall be of such depth as to permit cleaning. If possible, all bushings shall be so designed as to permit renewals. Bushings shall be scraped to fit the journals. Effective lubrication of journals shall be provided. Screw-feed grease-cups shall generally be used.

129. *Couplings*

Shaft couplings shall be of the claw or flange type. In general claw couplings shall be used, especially where the shaft runs from the centre of the span to the ends, or where deflections of the structural work would have a tendency to bend and bind the shafting. The two claws forming the coupling shall be finished for a close but not a tight fit. In flange couplings the two parts shall be connected by turned bolts with a driving fit. Flanges shall be shrouded so that the projecting heads of bolts may not be a source of danger. The hubs of couplings shall be one and eight-tenths (1.8) times the diameter of the shaft, but shall not exceed the said diameter plus ten (10) inches. The length of the hub shall be governed by the length of the key, but must never be less than the diameter of the shaft. All couplings shall be designed for the strength of the shafting they connect; and, in general, they shall conform to the dimensions in terms of "*d*," the diameter of the shaft, given in Figs. 78*b* and 78*c*.

130. *Collars*

Collars shall be employed where it is necessary to keep the shaft from moving horizontally. Two set-screws spaced one hundred and twenty (120) degrees apart shall be used in each collar.

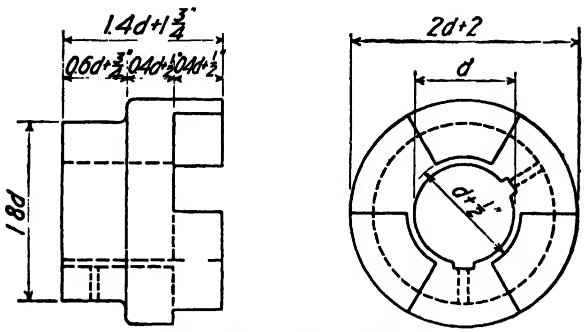

FIG. 78*b*. Jaw Coupling.

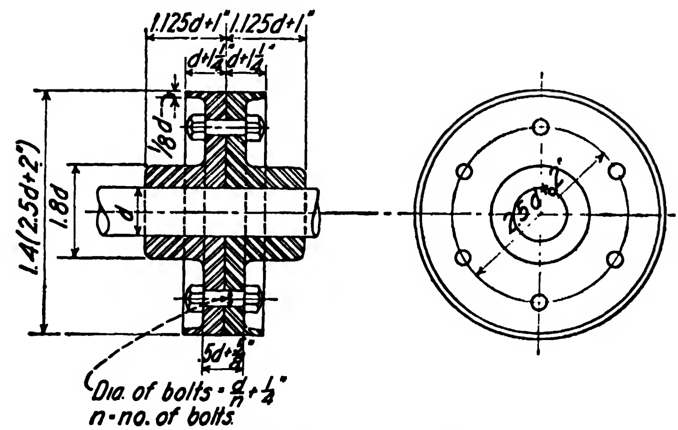

FIG. 78*c*. Flange Coupling.

131. *Friction Clutches*

Friction clutches of an approved standard make shall be employed where internal combustion motors form the motive power. They shall be of substantial construction and shall be capable of developing the maximum torque of the motor. (See also Paragraph 92.)

132. *Screws*

Screws which transmit motion shall have square threads.

133. *Levers*

Levers used in performing the various operations shall be located so as to be convenient for the operator. They shall generally extend about

five (5) feet above the floor, and shall be arranged to pull toward the operator. Latch levers shall be used where it is necessary for the lever to be held in more than one set position.

134. *Turned Bolts*

Turned bolts shall be employed where a shearing action exists, and their diameter shall be such as to provide for a driving fit in the holes. The diameter of the threaded portion shall be at least one-sixteenth ($^1/_{16}$) of an inch smaller than that of the shank of the bolt. All threads shall be U. S. standard V-threads. Unless specially noted to the contrary, all bolts shall have standard hexagonal heads and nuts. Lock-nuts shall be provided where there is any likelihood of the nuts becoming loose due to vibration or other causes. Cotters should be used through nuts when it is necessary to hold the latter in a permanent position. Washers shall be provided for all nuts; and where the latter bear on inclined surfaces, special bevelled washers shall be used. Washers shall also be provided where the bolts bear on wood. Bolt heads countersunk in castings shall be square. Wrenches shall be provided for all sizes of bolts; and these shall be part of the operating equipment.

135. *Tap-Bolts*

Tap-bolts shall not be used except by special written permission of the Engineer.

136. *Dust Covers*

Dust covers and safety guards shall be provided for all machinery.

137. *Shims and Drainage Holes*

All machinery, excepting only parts of minor importance, shall be supported on and bolted to the steelwork. Shims shall be provided where necessary for aligning and adjusting the machinery, and they shall vary in thickness by sixteenths of an inch as required.

Drainage holes of appropriate sizes shall be provided in all machinery parts where it is possible for water to collect and stand.

138. *Hand-Operating Levers*

Hand-operating levers shall be located for easy access and operation. The end lifting mechanism of swing spans shall be capable of being turned from the ends as well as from the centre of the span. As many levers shall be provided for the vertical shaft as are required to perform the necessary operation. They shall be about four and a half (4.5) feet above the floor. These levers shall be either of timber or of wrought-iron pipe, and shall be easily removable from the shaft. In cases where it is nec-

essary to remove the latter, it shall have a square socket at the lower end to engage a square shank on the driving shaft. In highway bridges the said shaft shall be protected by a suitable cover in the floor.

139. *Counterweights*

In bob-tailed draw spans the short arm must be counterweighted so as to balance the long arm. The counterweights shall be of either concrete or cast iron placed beneath the floor near the end of the short arm.

In lift spans the counterweight shall consist of either one or several concrete blocks at each end of the span. These blocks shall be cast in wooden forms on to a steel framework. The framework shall be suspended from the equalizers by eye-bars. This framework shall be so designed that when suspended from the hangers it will carry the weight of a block of concrete necessary to form a reinforced beam of such a section that it will support the remaining concrete placed above it. Where several vertical sections, or what is known as the sectional type, are used, a space of not less than two (2) inches shall be left between the sections. The upper ends of the sections shall be separated by links that connect to the bottom equalizer pins; and guides shall be attached near the lower ends so as to hold the sections together in a transverse direction.

The counterweights shall be made five (5) per cent lighter than the figured weight to be balanced; and balancing blocks to the extent of ten (10) per cent of the figured weight shall be provided for adjustment. These blocks shall be made so as to be easily handled by two men, usually about one (1) foot on each edge. They shall be provided with eye-bolts of ample size for inserting a hook for handling. These bolts shall generally be made of three-quarters ($\frac{3}{4}$) inch rods, and shall have an eye of two (2) inches inside diameter. The blocks shall be placed in wells at the top of the counterweight and no blocks shall project above the tops of the said wells.

The counterweight shall be guided at the inside face by substantial guides fastened to the steel frame or the concrete and engaging with tracks attached to the inside of the longitudinal tower bracing. Ample clearance shall be provided in the guides so that they will not bind as the counterweight changes its position in moving up and down.

The counterweight shall clear the floor by not less than three (3) feet when the span has reached its normal lift. In determining this distance the figured length of the ropes shall be increased by one (1) per cent for stretch in the ropes due to wear, etc. A clearance of not less than two (2) inches shall be provided between the counterweight and the steelwork of the tower.

Where it is advisable to provide for a possible future shifting of the river channel, necessitating a change in the location of the lift span, sectional counterweights formed of pre-cast blocks shall be used. The bot-

tom block shall be designed to carry the upper blocks, which shall be of such a size that they can be readily handled with the equipment that is likely to be available, the heaviest ones weighing in most cases not over two tons each. Their length shall generally be greater than their height, and their width about the same as that of the bottom block; and they shall have their inner contact surfaces beveled so as to produce a wedging effect when placed in position, thus assuring a tight fit. The blocks shall be provided with ample U-bolts for handling. Provision for adjusting the weight shall be made in the same manner as for solid counterweights. This same type of counterweight shall be adopted where it is desirable to cast the blocks on the ground and hoist them into place, even though the span be not designed for shifting in the future.

The counterweight shall be made of either stone or slag concrete. As a rule, stone concrete shall be used. It shall be assumed to weigh one hundred and forty-seven (147) pounds per cubic foot, exclusive of the steel. Slag concrete shall be assumed to weigh one hundred and seventy (170) pounds per cubic foot. In every case the approximate weight of the concrete to be used shall be ascertained before designing the counterweight.

In bascule spans the counterweight shall be of either concrete or cast iron, depending on the type of bascule under consideration. The concrete counterweights may be attached rigidly to the steelwork, or pivoted, depending, as before, on the type adopted.

140. *Machinery House*

In swing bridges and vertical lift bridges the machinery house shall usually be placed at the centre of the span, and in bascule bridges where most convenient, depending on the type of bascule adopted. The house shall generally be of fireproof construction, although in certain cases, where the danger from fire is very remote or where the money available for the structure is small, timber construction may be employed. The fireproof construction shall consist of a steel framework and floor system with the walls and floor of concrete, steel plates, or other non-combustible materials. In the timber construction steel floor-beams shall be used.

The house shall be of such size that there will be ample room for the machinery, work-bench, stove, and chair, and to provide easy access to all parts of the said machinery. Wherever shafts are located above the the floor, stiles shall be provided for crossing over them. The house shall contain ample window space so as to provide as much light as possible as well as to permit the operator to watch the traffic on both the bridge and the river. The windows shall be of a single pane in each sash. The house shall be made weatherproof; and where gears or other machinery project below the floor, the openings thus made shall be boxed in. In cold climates, especially when the operator has to remain within it con-

tinually, the house shall be heated. The heating may be done by stoves or by electric heaters. The roof of the house shall be properly drained, with down-spouts leading to the sides of the span. A convenient platform shall be placed outside of the house for storing supplies, etc. When the capstan for hand operation is outside of the house, the platform shall be made amply large to permit the men to operate it. It shall be of the same construction as the floor of the house.

Where the structure is of sufficient importance to warrant its installation, a five (5) ton crane running on tracks at the sides of the house shall be provided in the house.

141. *Walkways and Stairs*

Stairs shall be provided for access to both the operator's house and the machinery house, and walkways for access to all machinery outside of the latter.

142. *Operator's House*

In case the operator is not located in the machinery house, the operator's house shall be so placed that he can have an unobstructed view in all directions of the traffic on both the bridge and the river. The house shall be of the same construction as that described for the machinery house; and it shall be of ample size to accommodate the operator, and the controllers, levers, switchboard, indicator, stove, chair, and other equipment needed by him. The house shall be provided with ample window space.

143. *Gates*

Gates of substantial design shall be furnished and erected at the ends of all movable bridges for highway traffic. They shall be of neat design and built of structural shapes. There shall be four (4) gates, two at each end, swinging on pivots near the trusses. They shall be so arranged that two of the gates can be closed to the oncoming traffic and the other two closed after the movable span has been cleared of all passengers. The gates shall be controlled either by the operator or by gate tenders specially provided for the purpose. The gates shall be equipped with some form of lock or stop to hold them in both the closed and the open positions.

144. *Gate Tender's House*

Gate tenders' houses shall be furnished one at each end of the span for the convenience of the gate tender. They shall be of neat construction so as to conform to the general surroundings of the structure. They shall be of timber or, preferably, concrete construction, and shall be provided with stove and chair.

145. *Boat Indicator*

On one leg of the tower, on both the upstream and the downstream sides, and extending down on the pier to low water level, a gauge shall be painted in large figures for the convenience of the river traffic. An indicator at the lowest point of steel of the lift span shall show to the occupants of passing vessels the height on the gauge to which the span has been lifted. By noting the gauge reading at the water level one can ascertain readily the height of the span above the water.

CLAUSE INDEX OF CHAPTER LXXVIII

CHAPTER LXXIX

GENERAL SPECIFICATIONS GOVERNING THE MANUFACTURE AND ERECTION OF THE SUPERSTRUCTURE, SUBSTRUCTURE, APPROACHES, AND ALL ACCESSORY WORKS OF BRIDGES, TRESTLES, VIADUCTS, AND ELEVATED RAILROADS

SOME five years or more ago, in order to be prepared for any case of contract letting that might arise, the author undertook to draft for his firm seven sets of specification forms for the use of the office so as to enable the principal assistant engineers to aid in writing specifications for the current work; because up to that time all such documents had been prepared personally by one or other of the two members of the firm, and the task had become almost unbearably onerous in view of the fact that the bridgework under way in both office and field amounted in value at times to twelve and even fifteen millions of dollars. The seven sets of specifications mentioned were the following:

1. Manufacture of Superstructure Metal.
2. Manufacture and Erection of Superstructure.
3. Substructure.
4. Substructure and Erection of Superstructure.
5. Substructure, Manufacture of Metalwork, and Erection of Superstructure.
6. Erection of Superstructure.
7. Reinforced Concrete Structures.

After all these were finished, their mass (involving many hundreds of typewritten pages) was so appalling that it was decided to combine them into one document. In making the combination it was the intention to cover every feature of bridge building that had ever occurred or would be likely to occur in the firm's practice, including substructure, superstructure, approaches, and accessory works. This was done by the author personally; and from time to time he has since added a few clauses bearing upon questions that have arisen in the firm's operations. The final compilation is herewith presented in the hope that the reader may be able to use it in exactly the same manner as did the few of the firm's assistant engineers who were entrusted with the duty of specification writing.

It will be noticed that some of the clauses are complete and permanent. These are marked "P." Some are variable and are marked "V," and others are incomplete and are marked "I." In the case of each

"variable" clause, instructions are given as to how it is to be prepared for any particular case (or, in other words, there is drafted a general description of what the clause should contain), followed by an actual example taken from the author's practice to illustrate the application of the directions. The "incomplete" items require only that the blank spaces be filled in so as to make them complete. In some of the clauses certain words appear in **bold-faced type**; and these words may have to be omitted or modified in many cases. This remark does not apply to the words **Contractor, Engineer,** etc., in the Contract.

The order in which the various items are listed is about as logical in respect to continuity as it could be made, each item in some manner suggesting the one that follows, and the directions concerning the entire work specified being grouped to a certain extent in chronological sequence.

To use the form in preparing the specifications for building either the whole or any part of any particular bridge, one should begin at the first item and go through the entire list to the end, drafting the special items, filling out the incomplete ones and copying the permanent ones verbatim, omitting, however, all those which are not applicable to the case in hand. By so doing the writer will ensure that nothing of any importance is omitted, that his clauses are in fair sequence, that there are no duplications, and that his resulting specifications will cover the whole subject thoroughly and satisfactorily, provided, of course, that he has had the experience and possesses the ability necessary to do such important work as the writing of bridge specifications.

At the end of this chapter is given an alphabetical index of the various clauses which it contains, referring to them by their numbers. This is inserted for the convenience of any reader who may desire to use the chapter in the preparation of some particular bridge specification. In addition, however, the contents of the chapter are covered in detail by the general "Index" at the end of the second volume of the treatise.

After the manuscript of this chapter was finished and brought up to date, the author's attention was called to the paving specifications of the American Society of Municipal Improvements for 1914; and being convinced that there exists no higher authority on pavements than that society, he decided to modify certain of his paving standards so as to agree with its requirements, quoting in certain places therefrom nearly verbatim and making but few modifications.

SPECIFICATIONS

V. 1. *Location*

This clause should give for each structure the name of the stream, street, railroad, etc., to be crossed and the name of the city (or town) in (or near) which it is located; also the county and the State. If it be located in a country district, give the name of the nearest important

railway station and state how far distant it is, also in what direction therefrom the site lies. If the structure be a railroad bridge, give the name of the railroad company; but, if not, state for whom it is to be built. State whether the bridge is to replace an existing one, and, if so, who will remove the old structure, and when. If it be a city bridge, state the name of the street it is to occupy.

Example

The two bridges are about nine miles apart on the extension of the line of the Louisiana and Arkansas Railway in Catahoula and Concordia Parishes, Louisiana. The nearest railroad station at present is Black River Station, on the line of the St. Louis, Iron Mountain, and Southern Railway. The bridge over Black River is about one mile downstream, and that over Little River about ten miles upstream from this station.

V. 2. *General Description*

For the superstructure there are two types of general description to be employed, viz.:

A. When complete detail drawings accompany the specifications, and

B. When bids are called for in advance of the preparation of the complete detail drawings, in which case either special typical show drawings are prepared or old drawings of somewhat similar structures are offered as samples or guides to bidders in the determination of schedule prices for their tenders.

In "Type A" very few dimensions should be given in the specification. All that are necessary are the ruling ones, such as span lengths and perpendicular distances between central planes of trusses, or clear widths of roadways and sidewalks. No minor dimensions, such as sizes of stringers, weight or dimensions of handrails, or sizes of guards, should be given; for these can be obtained from the drawings. All descriptions, such, for instance, as those of operating machinery, should be very brief; but they should be ample enough to give the reader a clear idea of what the part described is like. This clause should indicate in a general way the characteristics of the construction.

In "Type B" the description should be gone into in very thorough detail, giving the number and sizes of all important parts, but taking care to indicate that the dimensions are either merely approximate or subject to change; in order that later, if modifications be desired, no reasonable objection to their being made can be raised by the contractor. Each kind of span in the design should be described separately, giving its length, the character of the construction (whether riveted or pin-connected), the number and lengths of panels, the truss depth, the perpendicular distance between central planes of trusses, the number, kind, and sizes of stringers or steel joists, the method of providing for expansion and contraction, the style of bracing in towers, the method of attaching longitudinal girders

to column tops, etc., referring, wherever practicable, to the accompanying drawing that illustrates the feature described. The hand-rails should be described fully; and in connection with them it is well to indicate that they are to be furnished at the same average price as the rest of the superstructure metal, in order to forestall a possible demand from the contractor for a higher schedule price, on the plea that it is customary to pay extra for metal hand-rails. In case there are any gates for shutting off travel when the moving span is to be opened, they and their operation should be fully described in this clause so as to avoid having to treat the same anywhere else in the specifications.

The machinery should receive particular attention, especially as it is likely to be different in many ways from the machinery used for illustration. It should be described systematically in all its parts and connections, and the horsepower should be stated within fairly close limits, bids for the motors, etc., being taken per horsepower. If hand-power operation is to be provided in addition to mechanical power, this should be pointed out.

In case of a lift span or other movable span of novel or unusual type, a complete description of its construction and mode of operation should be given.

The machinery house or houses should be described in detail, so that bidders can tender intelligently thereon either by lump sum or by schedule rates, according to whichever method of receiving bids on this part of the work has been decided upon by the Engineers.

In case that the structure is arranged for future widening or for the addition of roadways or sidewalks outside of the trusses, this should be pointed out and the method of future attachment described. This remark applies equally to both types of specifications.

The flooring or pavement of both the main roadway and the sidewalks, the guard angles, the system of lighting the structure, the drainage of the pavement, the provision for expansion and contraction, the protection of column feet of viaducts by cast-iron fenders filled with concrete or grouting, the railway rails with their splice-bars, bolts, tie-plates, ties, and spikes, the trolley poles and wiring, and the timber, both treated and untreated, should be fully described.

If the contract is to cover the approaches to the bridge, these also should be accurately described in complete detail, omitting no feature of any importance. Ordinarily, if the approaches be of timber, they will pertain to the superstructure contract, but if of concrete walls and earth filling, they will pertain to the substructure contract.

For the substructure of bridges this clause should cover the construction in the following order:

First. Layout of spans and piers, referring to the accompanying drawings.

Second. Character of the materials to be penetrated and the foundations to be reached.

Third. Method of sinking cribs or caissons.

Fourth. Characteristics of piers, pedestals, and abutments.

Fifth. Earth embankments or filling, if the same be included in the contract.

Sixth. All characteristics and special features of the crossing not specifically treated in other clauses.

For reinforced concrete bridges the directions are the same as for substructure, except that the fourth item thereof should read thus:

Fourth. Characteristics of spans, arches, piers, abutments, hand-rails, pavements, guards, sidewalks, cross-walls, ornamentation, drainage, provision for expansion and contraction, railway rails (with their splice-bars, bolts, tie-bolts, ties and spikes), lighting, and trolley.

In giving the data for substructure, if any thereof have to be verified by bidders, attention should be called as to which items of information are and which are not to be verified. For instance, it would not be right to ask bidders to check the results of the borings; but it would be perfectly proper to place on them the onus of verification of the locations of sand and gravel beds, the qualities of the materials to be found therein, the length of haul and the condition of the roads, the availability of suitable stone for rip-rap, and similar information given in the specifications.

It must be borne in mind that the more complete the data submitted to bidders, the more accurately they can make their estimates, and the lower, consequently, will probably be their tenders.

Example for Superstructure

The bridge over the Black River is to consist of five (5) through-truss, riveted, single-track, railway spans, each one hundred and sixty-five (165) feet long, supported on six (6) piers. One of these spans is arranged to be lifted between two towers, supported on the two adjacent spans, to a height sufficient to allow for the passage of river traffic. The lifting span will be suspended by eight (8) wire ropes at each corner, which pass up and over sheaves at the tops of the towers and are connected to two (2) counterweights of concrete and steel, exactly balancing the span. The operating machinery, which is carried on top of the lifting span at the centre, consists of four spirally-grooved drums, actuated through trains of gears by gasoline engine. Each drum controls two operating ropes; the one at the top leads over a sheave at the corner of the span, thence downward, and is fastened near the bottom of the tower; the one from the bottom of the drum leads under the same sheave at the corner of the span, thence upward, and is fastened at the top of the tower. All four drums are similarly connected, and when they are revolved in one direction the ropes leading to the tops of the towers are wound on, and those connected to the bottoms of the towers are payed off, thus raising the span by the lifting force exerted on the corner sheaves. Reversal of di-

rection of revolution of the drums lowers the span. Brakes with automatic stops control the movement of the span, and a hand brake is provided for manual control. The span may also be operated by hand in case of emergency.

The bridge over the Little River is to consist of three through-truss, riveted, single-track, railway spans, each 118 feet long, supported on four piers. One of these spans is likewise arranged to be lifted between two towers supported on the other two spans. This lifting span is supported and operated as described for the Black River span.

Example for Substructure

The bridge, the substructure of which is to be built under these specifications, will carry two standard railway tracks on its lower deck, and two street car tracks in a paved roadway and two sidewalks on the upper deck. The railway tracks approach the westerly end of the bridge on a fifteen-degree curve, which extends over two deck, plate-girder spans and ends on the westerly main channel span; thence they continue on tangent to a point about two-thirds of its length across the easterly channel span, where they turn out in both directions on sixteen-degree curves.

The street railway and highway approach begins at the westerly end at the easterly side of Third Street and is carried, first on an embankment, then on a steel trestle parallel and immediately alongside Glisan Street, thence across the river on the upper deck of the three main channel spans, and thence on steel trestle to its easterly end at the junction of Oregon and Adams streets.

The substructure required consists of the retaining walls, abutments, and seventeen pedestals for the westerly street railway and highway approach, an abutment and a pier for the westerly railway approach, a westerly shore pier, two mid-river piers, and an easterly abutment to support the main channel spans, and ten pedestals and an abutment for the easterly street railway and highway approach.

The bases of both end abutments and all pedestals, except the three next the westerly shore, are near or above the high-water elevation; hence they may be constructed in open excavations. The three pedestals, the abutment, and the two piers next the westerly shore will be supported on piles, and excavations for them will be made through cribs by open dredging. The two main channel piers will be sunk by the open-dredging process to a bed of cemented gravel lying about one hundred and twenty to one hundred and thirty feet below low-water level. The abutment at the easterly shore will rest on a bed of cemented gravel which is found but ten to twenty feet below low-water level. The piers will be constructed of concrete with granite caps. The abutments will be of concrete with granite bridge seats, and the pedestals and the retaining walls for the westerly approach will be of concrete throughout.

Example for Reinforced Concrete Bridge

The structure consists of 8 reinforced concrete arch spans, each 110 feet long in the clear, or 118 feet 9 inches from centre to centre of piers, the total length between springing lines at abutments being 941 feet 3 inches. Three of the piers will be supported on piles, which are to be driven by water-jet, as described herein. The other four piers are to be carried to bed-rock. The concrete shaft of each pier rests on a mass of concrete below low-water level, which mass is enclosed in a box composed of 12″ × 12″ timbers encasing the heads of eight rows of piles, as shown on the drawings, where piles are used beneath the piers. The length of the piles there indicated is thirty feet, but the actual length to be used cannot be determined except by trial. The Contractor will be required to put in as long piles as can be driven by water-jets and hammer combined without involving unusual difficulty and expense. He will be paid for the cut-off ends according to the terms of the clause for "Unclassified Work." The depths to which all piles are to be driven will be determined solely by the Engineers.

As there is to be no direct payment for the timber bases of the piers, the Contractor will be at liberty to use sheet piling instead, provided the Engineers deem this satisfactory. Unless the Engineers decide that so doing would injure the foundations, the sheet piling may be withdrawn; but in such cases the voids thus left must be filled with small broken stone or tamped gravel in order to avoid inducing scour.

The main dimensions of all piers and abutments are shown on the accompanying drawings.

At the top of each pier, immediately below the arches, is a coping surmounted by a cocked hat at each end, and above this is a narrow ornamental wall which appears to be a continuation of the pier. Above the arches, which are 24 feet 6 inches wide, rise narrow transverse walls to support the floor.

The main roadway, which is ultimately to carry a double-track electric railway, is 30 feet wide in the clear; and on each side of the bridge there is a footwalk 5 feet wide in the clear, which, with a portion of the roadway, is cantilevered out beyond the arches and cross-walls by beams of reinforced concrete. The end arches of the bridge spring from concrete abutments of the type shown on the drawings. The face of the abutment next the city will lie in the same plane as the face of the retaining wall which is already constructed. A cheap concrete backing will be used for the abutments in order to increase their mass so as to resist properly the thrust from the arches.

The cross-walls support a slab of reinforced concrete, upon which is a thin layer of sand to carry the concrete base for the block pavement, all as shown on the drawings. The railroad tracks will not be put on at

present. The block pavement will be described further on. Above the cantilever brackets of the sidewalk is a slab of reinforced concrete carrying a mass of sand, upon which rests the granitoid footwalk. Between the latter and the lower slab is space that may be occupied by water pipes, gas pipes, or telephone conduits, as indicated on the drawings. The hand-rails are to be of concrete of an ornamental character, as shown.

I. 3. *Changing of Grade*

The grade of the new structure is to be . . . . feet **higher (or lower)** than that of the present bridge; and the Contractor must so handle his field operations that the changing from the old to the new grade will not interfere materially with traffic.

V. 4. *Temporary Bridge*

Sometimes it is necessary that the Contractor build a temporary bridge or trestle to take care of the traffic before beginning to demolish the old bridge. In such a case there should be here given a thorough, descriptive, general specification for the said temporary bridge or trestle; but the detail specifications for its construction need not be included in this clause, because they will be found farther on in these specifications. In building temporary structures it is often permissible to use inferior or second-hand materials, and to what extent this may be done should be made clear in this clause. Again, for temporary work it is not necessary to protect the wood against decay as specified for permanent timber constructions. Should any job be divided among two or more contractors, the duties of each in connection with the temporary bridge must be clearly defined.

EXAMPLE

As shown on Drawing 19, it will be necessary to build a timber trestle connecting the ends of the present draw span with the present wooden trestle on the east end and with Eleventh Street and Cliff Avenue on the west end, in order to maintain traffic during the construction of the new bridge.

The present structure consists of two fixed spans and a swing span over the waterway, and a steel trestle or viaduct at the west end, all pin-connected. The contractor for the substructure shall remove the two east piers and the pier between the draw pier and the west pier of the present bridge; and he shall remove the two fixed spans and the trestle at the west end of the bridge. The swing span will be swung through an angle to connect to the ends of the temporary wooden trestle. The contractor for the substructure shall also furnish all materials for and construct and maintain during the continuance of his operations the temporary wooden trestle, and thus maintain traffic on Eleventh Street from the present timber trestle at the east end to Cliff Avenue at the west end.

The contractor for the erection of the superstructure shall remove the draw span and the pier supporting it and the draw protection; and he shall maintain the temporary trestle from the time the substructure contractor has been relieved of that duty by the city; then he shall remove the temporary trestle, the materials in which shall become his property.

V. 5. *Removal of Old Structure*

It often occurs that the Contractor has to take down the old spans and even remove the old piers. In such a case a complete specification for such removal should be drawn, and in it should be clearly stated what is to be done with the old materials and who is to do the various handlings thereof. Again, it should be made clear who is to be the owner of the old materials. Sometimes it is better to let the Purchaser keep either the whole or a portion of them, but at other times it is better to let all of such materials become the property of the Contractor. In the latter case care should be taken to specify where he can and where he cannot store them, and how long they may be left at any place where stored temporarily. In the case of old wrought-iron bridges the metal is useful and valuable for blacksmith work, but old steel is good for nothing but scrap. Old masonry can often be employed for rip-rapping piers on pile foundations. Old timber may be valuable for falsework, or other construction, but generally it is fit only for firewood. Before settling what is to be done with the old materials the Engineers should consult their principal, the Purchaser, and obtain his decision on the matter. If the old superstructure is to be re-erected, this clause should specify how it is to be match-marked, paint-marked, piled, and loaded so that the metal may be properly kept track of for future use.

In respect to the removal of old piers and abutments, the elevation or elevations to which they are to be taken down should be stated; and it should also be made clear whether the piles are to be drawn or to be cut off at a certain elevation.

Example

The old masonry abutments shall be removed to one foot below ground surface, and such parts of the material as the engineers may designate shall be placed in dry walls at the foot of the embankments. All other materials in the old bridge, except the metalwork and bolts, are to be the property of the Contractor. The old steel span is to be match-marked and carefully taken down; and all parts thereof, together with all bolts in the timber floor, are to be stored in an orderly manner at a point on Troost Avenue within 300 feet of the bridge, in accordance with the directions of the Engineers.

V. 6. *Remodeling of Substructure*

Occasionally the Contractor is required to remodel the tops of old piers, in order to raise or to lower them or to strengthen them so as to carry

properly the new loads. In this case a complete specification should be drawn covering the entire work of such remodeling. Permission for using dynamite for taking down the old masonry should be either given or withheld, as the Engineers deem preferable. The item of repointing the old masonry that is left in should be considered. The method of rebuilding the pier tops with concrete should be fully explained. Sometimes it is advisable to strengthen the new tops of the old piers by embedding old rails in them, which rails are the property of the Purchaser. In such a case the conditions governing the obtaining and the use of these old rails should be thoroughly explained in this clause. It should be stated how, when, and where the said old rails are to be delivered to the Contractor and what he is to do with them after they are so delivered.

Example

Nine masonry piers for a high-level bridge were built on this site several years since. The bridge to be built now is to be of the double-deck type, having the lower deck at a much lower level than the original plan provided; and the grade of the upper deck varies from that shown on the original plan. Therefore it is necessary to increase the height of bridge seat by building up the masonry on some piers and to reduce it on others by removing the tops of the piers; and in some instances steel girders will be placed in the tops of the piers to assist in distributing the load.

The work to be done under this contract is as follows:

A. Build three concrete abutments, one on each side of Second Street and one on the south side of First Street.

B. Place in the position and elevation required on top of Piers I and II, steel girders, which the Company will furnish, build up the piers about the girders with quarry-faced masonry, and fill in beneath and around the girders with rubble masonry or concrete, all as shown in outline on Drawing No. 57.

C. Build up Pier III with quarry-faced masonry and concrete or rubble masonry backing, as shown in outline on Drawing No. 57.

D. Remove the tops of Piers IV and V, replace several courses of masonry, and place in the new tops of the piers steel girders, which the Company will furnish, all as shown in outline on Drawing No. 55.

E. Remove the tops of Piers VI and VII and replace several courses of masonry, as shown in outline on Drawing No. 55. No steel girders will be required in these piers.

H. Remedel Pier VIII, situated on the south side of the Wabash railroad tracks, substantially in accordance with Drawing No. 60. If the location of the north approach should be changed, a new concrete pier or a pair of large concrete pedestals shall be constructed instead.

I. Remodel Pier IX, situated on the north side of the Burlington railroad tracks, as noted on Drawing No. 61, and build two wings of

quarry-faced masonry with rubble or concrete backing, in order to form an abutment for the earth fill in the north approach.

J. Build or alter any other masonry for the bridge that the Company may desire built or altered.

The materials to be removed from the present piers shall remain the property of the Company. The Contractor shall use in the remodeling of the present and in the construction of the new masonry such portions of the stone removed from the present piers as the Engineers may deem suitable; and the remainder of the materials removed from Piers IV, V, VI, and VII shall be deposited on the Company's property where the Engineers direct. The unused materials from Pier VII shall be placed on the north side and those from Piers IV, V, and VI on the south side of the river.

The existing piers are to be remodeled as above described and as shown on the drawings. All the rebuilding is to be done in a truly first-class manner and to the satisfaction of the Engineers. In removing the stones care is to be taken not to injure in any way either the pier or any of the stones that are to be utilized in rebuilding.

V. 7. *Remodeling of Superstructure*

Occasionally it becomes necessary, in replacing an old bridge, to retain a portion of the superstructure. In such a case a full description, with drawings, should be prepared for such replacement, and detailed directions should be given concerning its *modus operandi.*

Example

The work of remodeling the superstructure of this bridge consists of the following:

A. Building falsework under each span so as to support it and carry trains during the reconstruction.

B. Removing and replacing certain vertical posts and diagonals as marked on the accompanying plans.

C. Strengthening the floor-beams by adding cover plates to the top and bottom flanges.

D. Doubling the stringers.

E. Removing and replacing the portal bracing.

F. Painting all new metalwork.

G. Removing of débris.

All the work to be done is indicated clearly on the accompanying plans, which show perfectly which is new construction and which is old. The new metalwork is to be manufactured in strict accordance with these specifications, and is to be put in place in a manner satisfactory to the Engineers. All fieldwork is to be conducted in accordance with the requirements of these specifications for new work.

V. 8. *Furnishing of Materials by the Purchaser*

In some cases certain materials, such as cement, rails, angle-bars, rail-bolts, and rail-spikes, are to be furnished by the Purchaser and put in place by the Contractor. Under such conditions there should be a clause with either a general heading like the above or a special heading in relation to the particular material to be furnished. The clause should specify that the Contractor must receive, haul, and store such materials and be responsible therefor until the completion of the entire contract.

Example

The Railroad Company will furnish the Contractor on its side-track at Sunshine Station all the cement required for the work, but the Contractor must receive, unload, haul to site, and store it until required for use; and he will be held responsible for its being kept in good condition until then. The Contractor will be allowed three (3) days in which to empty each car of its load of cement, after which he will be charged the usual demurrage.

V. 9. *Maintenance of Traffic*

In reconstructing an old bridge it is almost always necessary to maintain the traffic crossing the structure as well as to provide against interference with other traffic indirectly affected by the construction. Navigable waterways, public highways, private rights-of-way, etc., crossed by a structure, cannot be obstructed except by special permission granted by the proper authority; and, as a rule, it is necessary to carry on the erection without such interference. This is also true in a new structure. This clause should state the kinds of traffic to be dealt with and the precautions to be taken in each case.

Example

The Contractor must so conduct all of his operations as to interfere to the least extent practicable with the passage of boats, rafts, railway trains, vehicles, animals, pedestrians, and all other kinds of public traffic; and he must take every precaution against accidents happening to the said boats, rafts, trains, vehicles, animals, pedestrians, and other traffic because of his operations. No thoroughfare of any kind shall be closed without the written consent of the proper authorities.

V. 10. *Maintenance of Sewers and Pipes*

In constructing a bridge existing water-pipes, sewers, or conduits may have to be moved or temporarily supported. This clause must clearly state

who is to perform this work, and whether there is to be any direct payment therefor.

EXAMPLE

Unless otherwise agreed upon in writing, the Contractor shall maintain and leave in good condition any sewers, pipes, or other conduits uncovered or disturbed by his operations; and, if necessary, he must remove the old ones and build new ones. Such removal and building shall be treated as "Unclassified Work," unless there be schedule prices to cover them in the Contractor's tender, or unless some special agreement for the work involved be entered into by the Contractor and the Purchaser (either personally or through the Engineers).

V. 11. *Side-Tracks*

In this clause there should be stated what facilities exist for building side-tracks for unloading materials, who is to build them, and at whose expense. Generally the railroad company puts them in at its own expense and removes them after the work is completed; but sometimes the Contractor has to put them in either at his own expense or at that of the Purchaser.

EXAMPLE

The Purchaser will furnish the Contractor with all the rails, switches, angle-bars, bolts, spikes, and ties required for building 2,450 lineal feet of side-track; and the Contractor will be required to do the necessary grading and lay the track. After the structure is completed the Contractor, at his own expense, is to take up and store at Walhachin Station, as directed by the Purchaser, all the said track material and leave the same in good order.

V. 12. *Storage Facilities*

In this clause should be stated what storage facilities exist or may be had in the neighborhood of the bridge site; and if the Engineers know what the cost thereof would probably be, they should state it, but at the same time they should make it clear that the Purchaser is not to be held responsible for the correctness of the statement.

EXAMPLE

It will be necessary to build a short, temporary track from the site close to low-water line around to a small flat lying between the site and the town of Lytton. This ground is somewhat broken, and is by no means ideal for storage, but it is the best that can be had. As it is useless for cultivation, being covered with boulders, there will probably be no charge for rental. However, the Purchaser does not guarantee this.

V. 13. *River Conditions*

In this clause should be given a straightforward statement of what the conditions of the river generally are at the different seasons. The bidders should be told honestly what troubles they are liable to encounter; but at the same time they should not be frightened into putting in high bids by any unnecessarily alarming statements.

EXAMPLE

The Government records show that the low-water period is during the months of August, September, and October, and that the variation due to tide reaches approximately two feet at low-water season, but at high-water season the effect of tide is negligible. The fall and early spring high waters are usually from the upper Willamette, and are accompanied by considerable current; but the late spring high water is ordinarily back water from the Columbia River. Accompanying these specifications is a chart showing the record of gauge readings as taken by the U. S. Government.

In preparing his tender each contractor is to be governed by his own judgment of probable river conditions; and the actual resulting conditions will in no way be considered as unforeseen.

V. 14. *Transportation over Purchaser's Lines*

In this clause should be stated whether men, materials, and plant are or are not to be hauled free of charge over certain enumerated railroad lines that are owned or controlled by the Purchaser.

EXAMPLE

The Purchaser will haul both ways, free of charge, all of the Contractor's men, materials, and plant which may be used either directly or indirectly in connection with the work covered in the contract, on the following lines of railroad. . . . . .

V. 15. *Engine Service*

In this clause should be stated whether the Contractor is to receive engine service free of charge or, if not, how much he is to pay per diem for each engine with its driver and stoker. Generally it is better to have the Contractor pay the Purchaser for engine service, so as to prevent his keeping the engine and crew hanging around idle while waiting for the Contractor to finish portions of the work. On the other hand, though, every part of a day occupied should count for a whole day, because the unoccupied portion would probably be wasted by the engine crew.

EXAMPLE

The Purchaser will furnish the Contractor, at the rate of.......... dollars ($........) per day, engine service (including one locomotive, one driver, and one stoker, with fuel, oil, waste, and all such supplies) for placing cars to unload material, for taking down, transporting, and storing of the metal of the old structure, and for moving plant and materials for the new work. Each portion of a day that an engine and crew are employed shall be paid for as a whole day.

V. 16. *Routing of Freight*

In this clause should be stated by what railroad or railroads the materials are to be transported, provided that the favored route is no more expensive to the Contractor than any other. It is only occasionally that this restriction is placed in bridge specifications; but when their principal is a railroad company, the Engineers should always ask whether there are any instructions to be given concerning the routing of freight.

EXAMPLE

Provided the Contractor be put to no extra expense thereby, the metal is to be shipped from Pittsburgh to St. Louis by the Pennsylvania System, from St. Louis to Texarkana by the Missouri Pacific System, and from Texarkana to destination by the Kansas City Southern Railway Company.

V. 17. *Customs Duties*

When the metal work or other material is to be delivered in a foreign country, the specifications invariably should state who is to pay the customs duties.

EXAMPLE

The prices named in the Contractor's tender must cover the customs duties on all imported materials and plant used in the construction of the bridges.

V. 18. *Patents and Royalties*

When any patented articles are to be used on the work, the specifications invariably should state who is to pay the royalties thereon.

EXAMPLE

With the sole exception of any patents that may be owned or controlled by the Purchaser's Engineers, the Contractor is to pay all royalties charged for the use of patented articles employed in manufacturing or building the structures.

V. 19. *Observance of Labor Laws*

The Contractor throughout his operations shall comply with all labor laws and restrictions of the City, County, and State in which the work is being done, and must hold the Purchaser harmless against all fines and penalties incurred by the Contractor for the infraction of such laws and restrictions.

(N. B.) In certain cases the preceding restrictions will suffice, but in others it is better to be more specific, thus:

EXAMPLE

The Contractor shall not employ on the work, either directly or indirectly, any Asiatic or any person of the Asiatic race.

No work whatever shall at any time or place (except in the case of dire necessity when danger to life or property is involved) be carried on during Sunday, and the Contractor shall take all necessary steps for preventing any foreman, or agent, or workman, or other employee, from working or employing others on that day. The Purchaser shall in no way be held responsible for any infraction by the Contractor of these or any other labor restrictions.

I. 20. *Limits of Daily Labor*

The Contractor shall not employ upon the work or in connection therewith any workman or employee for more than.......... (....) hours per day of twenty-four hours. The working day shall commence at...... o'clock, A.M. and shall end at ...... o'clock P.M. If two or more shifts of men are working in one day, the same men shall not be permitted to work on more than one shift. Overtime shall not be allowed under any pretense whatever, except when human life is in jeopardy or when property is in danger of destruction. In such cases overtime will be allowed until the work is secured from danger, but no longer.

I. 21. *Rates of Wages*

The Contractor shall pay or cause to be paid to any workmen, artisans, mechanics, or laborers, employed by him on or in connection with this work, a rate of wages not less than that generally accepted as current in .... for competent workmen, artisans, mechanics, or laborers when employed on similar work.

V. 22. *Sources of Supply for Materials*

It often helps bidders in preparing their tenders to have in the specifications a clause stating where many of the various materials required

for the work may be obtained conveniently; but it is well to give, if possible, a choice of places so as to prevent monopoly and its consequent excess expense to the Purchaser.

EXAMPLE

Good, clean sand can be found in a bank about three-quarters of a mile from the bridge site; and there is a fairly good road with a continuous down grade from the said bank to the site. Gravel of satisfactory character is obtainable in large quantities from a bar about half a mile up-stream, but it will require washing. Broken stone can be brought in by rail from a quarry ten miles distant, but will have to be transported by wagon a full mile from the railway station. There is no local timber available, hence what is needed will have to be brought from the coast by rail.

V. 23. *Prices of Materials*

It is often advisable to state the prices at which the materials required for construction can be bought, but as a matter of precaution no responsibility to the Purchaser or the Engineers should be assumed by making the statement.

EXAMPLE

The following prices of materials, delivered on cars at various stations of the Purchaser's line, are furnished to bidders as a guide in preparing their tenders; but it is understood that the Purchaser in no way guarantees their correctness:

Portland cement......................	$1.65 per bbl.
Long-leaf yellow pine timber............	18.00 per M. ft. B. M.
Short-leaf yellow pine timber...........	15.00 per M. ft. B. M.
Long-leaf yellow pine piles.............	.08 per lineal foot
Oak piles, from 30 ft. to 40 ft. long......	.15 per lineal foot
Gravel.............................	.50 per cu. yd.
Sand..............................	.25 per cu. yd.

P. 24. *Spirit of the Specifications*

The nature and spirit of these specifications are to provide for the work herein enumerated to be fully completed in every detail for the purpose designed; and it is hereby understood that the Contractor, in accepting the contract, agrees to furnish any- and everything necessary for such construction, notwithstanding any omission in the drawings or specifications.

V. 25. *Modus Operandi of Construction*

If no *modus operandi* of construction has been laid out in advance, the following clause should be adopted:

"The *modus operandi* of construction shall be determined by the Engineers; but, so far as possible, it is to be arranged to suit the convenience of the Contractor."

But if there is determined in advance a well-formed policy of procedure, it should be given in detail, as, for instance, in the following:

EXAMPLE

On account of the short duration of the low-water season, the sinking of pneumatic piers will have to be begun simultaneously on both sides of the river about the first of September and finished about the fifteenth of January. Two full pneumatic outfits will be required, and the sinking will have to be pushed with the utmost dispatch. Each pier must be brought above extreme high-water level before the work on the construction of the shaft ceases temporarily. As the stream, though deep at high water, has no great velocity of current, it will be practicable to work on the completion of the shafts during the high-water season.

It will not suffice to delay the construction of the piers and pedestals of the approaches until the high-water season, because it will be necessary to start the erection of the said approaches about the beginning thereof. Moreover, as the approaches are to be used for transporting the metal of the main spans to the river bank, and as there is need for the greatest haste in the completion of the structure, it will be necessary to start the erection of the approaches simultaneously from the outer ends so as to complete them by the time that the river piers are finished.

V. 26. *Accompanying Drawings*

Give in some systematic order a list of all the drawings that accompany the specifications, and state whether these are or are not the complete detail drawings to be furnished by the Engineers. If they are not, indicate which are specially prepared for the contemplated construction and which are drawings of old, similar structures that are offered as samples of what the work will be like. This is important, so as to anticipate the Contractor's possible claim for extra compensation, based on the plea that the actual work has differed from that illustrated in the bidding drawings.

EXAMPLE

The following drawings accompany and supplement these specifications:

General and Substructure Drawings and Stress Sheets

1. General Plan and Profile, Black River Bridge.
2. General Plan and Profile, Little River Bridge.
3. Location Map, Black River Bridge.
4. Location Map, Little River Bridge.

5. Substructure, Black River Bridge.
6. Substructure, Little River Bridge.
7. Diagram of Stresses and Sections, Black River Bridge.
8. Diagram of Stresses and Sections, Little River Bridge.

Typical Detail Sheets

10. Counterweights, City Waterway Bridge.
13. Floor System 201-ft. Span, Keithsburg Bridge.
14. Trusses 201-ft. Span, Keithsburg Bridge.
24. Trusses, 114-ft. Span, Keithsburg Bridge.
29. Details of Towers, Keithsburg Bridge.
30. Details of Towers, Keithsburg Bridge.

Machinery Drawings

M1. Tower sheaves, shafts, bearings, equalizers, ropes, and rope sockets for Black River Bridge.
M2. Tower sheaves, shafts, bearings, equalizers, ropes, and rope sockets for Little River Bridge.
M3. General arrangement of operating machinery for Black River and Little River bridges.
M4. Mechanical Indicator for Black River and Little River bridges.
M5. Guide Rollers for Puyallup River Bridge (illustrative for guide rollers).
26. Centring Castings for Keithsburg Bridge (illustrative for thrust castings).
41. Rail Locks, Keithsburg Bridge (illustrative for rail locks).

Nos. 1 to 8 inclusive and M1, M2, M3, and M4 have been prepared specially for the two proposed bridges; but the others are offered merely to show the character of the details, in order that bidders may tender on the work at unit prices.

V. 27. *Detail Drawings*

If the complete detail drawings are not submitted to the bidders, the following clause is to be used under this heading:

"As soon as practicable after the contract for building the structure is signed, the Engineers will furnish complete detail plans, in strict accordance with which the Contractor shall prepare his shop drawings or his working drawings."

Sometimes, however, it is advisable to state exactly when the drawings will be ready.

V. 28. *Working Drawings*

The wording of this clause will depend on the type of structure to be built. It should fix the responsibility of the Contractor in regard to the checking of the Engineer's plans, should determine the plans to be pre-

pared by the Contractor, should give the procedure for approving plans and revising them after they are approved, should provide for the changing of plans and the compensation for such changes in the event that it becomes necessary to make alterations after they are completed, and should specify the plans that are to be furnished by the Contractor.

Example 1

No alterations shall be made in the general or detail plans without the written consent of the Engineers. The Contractor shall carefully check the Engineers' plans before beginning the preparation of his working drawings, and should any errors be found he shall bring them to the attention of the Engineers, who will make the necessary corrections, after which the Contractor shall be responsible for all errors which may occur or which may have occurred. The Engineers shall have the right to alter the plans as they may see fit, if further investigation of the conditions affecting the structure should so warrant; and they shall be at liberty to make minor changes in all plans during fabrication without any extra charge for the same being made by the Contractor, unless, in the opinion of the Engineers, the Contractor be really entitled to extra compensation on account of such changes. If practicable, the amount of such extra compensation shall be agreed upon in writing by the Engineers and the Contractor before the unanticipated work is started.

The working drawings shall be sent in duplicate for the approval of the Engineers, who will retain one set and return the other after checking them and marking thereon any changes or corrections desired. If any such changes or corrections are necessary, the drawings shall be corrected and prints again sent in duplicate to the Engineers; and this process shall be continued for any drawing until the Engineers have returned to the Contractor an approved print thereof. As soon as this approved print of any drawing has been received by the Contractor, he shall at once send to the Engineers as many additional prints as they may require. Should revisions in any drawing be made at any time, the Contractor shall send to the Engineers for their approval two prints thereof having the said revisions plainly noted thereon, and shall continue to furnish additional sets of duplicate prints until the approval of the engineers to the revised drawing is obtained. After the said revised drawing has been finally approved, the Contractor shall at once send to the Engineers as many additional prints thereof as they may require. At any time during the progress of the work, the Contractor shall furnish without charge as many sets of working drawings as the Engineers and other officers of the Purchaser may desire.

Should the Engineers prepare any working drawings, they shall be carefully checked by the Contractor; and if any errors be discovered, the Engineers' attention shall be called thereto. After the proper correc-

tions of these are made, the Contractor shall be responsible for all errors which may occur or which may have occurred.

With his working drawings the Contractor shall furnish an erector's diagram which shall show clearly the marking and position of each member of the bridge, also a camber diagram.

Upon the approval of the working drawings, but not before, work on the structure may be begun; and it is expressly provided that such approval shall in no way release the Contractor from responsibility for drafting or shop errors. After the plans have been approved, alterations will be permitted only upon the written instructions of the Engineers.

The Contractor shall prepare complete detail plans showing shape, dimensions, and position of all reinforcing bars, and shall design and prepare full working drawings for all forms, falsework, and staging, and for all erection equipment; and these drawings must be made to meet the approval of the Engineers before construction begins.

Before the constructions are accepted, the Contractor shall furnish to the Purchaser, without charge, one complete set of all shop drawings and all working drawings printed on cloth.

Example 2

The Contractor shall prepare all detailed working drawings required to enable him to fabricate, erect, and construct all parts of the work in strict conformity with the Engineers' drawings and with these specifications.

These working drawings for structural steel and machinery shall include, in addition to the necessary shop drawings, camber diagrams and erection diagrams which show clearly the marks and position of each member.

For reinforced concrete construction, the working drawings shall show the dimensions, shape, position in the work, and means of supporting in position of all reinforcement, and all forms and the means of supporting them.

For substructure and all general construction the working drawings shall show all minor and special details which are left open to the Contractor's choice of methods of construction or which for any reason are not fully shown on the Engineers' drawings.

For all construction the Contractor's working drawings shall show details of falsework, rigging, and all other temporary structures, and sizes, capacities, and other characteristics of all machinery and plant employed.

Working drawings shall be submitted to the Engineers in duplicate; one set will be returned to the Contractor approved, or showing the changes or corrections required; duplicate copies shall be resubmitted after correction, until they receive the Engineers' approval. Working drawings shall be corrected or revised whenever and however the Engineers direct, but no approved working drawings shall be altered and

the Engineers' drawings shall not be deviated from without the written consent of the Engineers.

The Contractor shall carefully check all drawings, the Engineers' as well as his own, and if any errors be found they shall be reported to the Engineers, who will make or approve the necessary corrections. The Contractor having undertaken to construct a structure complete and adequate for the purpose intended, and having checked all plans, shall be responsible for the correctness of all drawings; and it is expressly understood that the Engineers' approval of the drawings does not in any measure relieve the Contractor of full responsibility for errors.

Payment for working drawings shall be included in the prices for materials named in the contract. For minor revisions of completed and approved working drawings no extra payment will be made; for material revisions for which, in the Engineers' opinion the Contractor is fairly entitled to extra compensation, the Engineers will fix the amount that the Purchaser shall pay and the Contractor accept as full payment for such revisions.

The Contractor shall furnish without additional charge two complete sets of cloth and as many sets of paper blueprint copies of the working drawings as the Purchaser and the Engineers may desire.

P. 29. *Alteration of Plans*

The Engineers shall have the power to vary, extend, increase, or diminish the quantity of the work, or to dispense with a portion thereof during its progress without impairing the contract; and no allowance will be made the Contractor except for the work actually done. In case any change should involve the execution of work of a class not herein provided for, the Contractor shall perform the same as provided for in the clause entitled "Unclassified Work." In such cases the Engineers will first give a written order, and the Contractor must furnish them with satisfactory vouchers for all labor and materials expended on the work.

P. 30. *Changes*

All clauses of the specifications and contract shall apply to any changes, additions, or deviations, in like manner and to the same extent as to the works at present projected; and no changes, additions, or deviations shall annul or invalidate either the contract or the bond.

P. 31. *Workmanship and Materials*

It is the intent of these specifications to provide for first-class materials and workmanship of every kind in all parts of the structure, and both shall be subject to the inspection and approval of the Engineers at any time during the progress and until the final completion of the work. The

entire work shall be constructed in a substantial and workmanlike manner in strict accordance with these specifications, the accompanying plans, and such instructions as may be given from time to time by the Engineers, and to the satisfaction and acceptance of the Engineers. The Contractor shall employ suitable mechanics for every kind of mechanical work, and shall, at the request of the Engineers, discharge from the work any foreman or workman whom the Engineers shall deem incompetent, negligent, or untrustworthy.

P. 32. *Inspection in General*

All materials and all processes of manufacture or construction are to be subject to the inspection of the Engineers at all times; and the Engineers and their inspectors shall have free access to all parts of any factories or plants in which any materials are being manufactured or prepared, and to all parts of the work of construction and erection. All facilities for the desired inspection of materials or workmanship shall be furnished by the Contractor as requested. The Engineers or their representatives will pass on all materials of every kind before their use in the structure, and any rejected material must be removed at once from the site or the vicinity of the process of work, or from the right-of-way. The operations of manufacture, construction, and erection will likewise be inspected; and all workmanship or processes deemed to be faulty must be corrected immediately on request.

P. 33. *Inspection of Metal*

All metal will be inspected at the mills and shops. The inspection and tests of all metal will be made promptly on its being rolled or cast, and the quality will be determined before it leaves the rolling mill or foundry.

Material which, subsequent to the tests at the mills and foundries, and to its acceptance there, develops weak spots, brittleness, cracks, or other imperfections, or is found to have any injurious defects whatsoever will be rejected at the shops and shall be replaced by the Manufacturer at his own cost. The inspection of workmanship will be made as the manufacture of the material progresses, and at as early a period as the nature of the work will permit. The Contractor must furnish all facilities for inspecting the workmanship and testing the quality of all material furnished on the order at the mill or shop where the said material is manufactured; and the Engineers and their Inspectors shall have free access to all parts of the plants in which any portion of the material is being made. All tests are to be made by the Contractor for the Inspector without charge.

No material shall be rolled or work done before the Engineers and the Inspector have been notified where the orders have been placed or before arrangements have been made for the inspection. Complete copies of

mill orders and plans must be furnished to the Inspector, and he must be notified in time to be on hand when work is begun on his order. Any delay on the part of the Inspector shall be reported to the Engineers, but no material will be accepted which has not been passed upon by the authorized representative of the Engineers.

P. 34. *Inspection of Other Materials than Metal*

All other materials, processes, and workmanship than metal and machinery and their manufacture shall be inspected at the bridge site, unless the Contractor should elect to have any materials, processes, or workmanship inspected elsewhere, in which case such inspection shall be performed by the Engineers at the places designated by the Contractor; but all expenses incurred in making such inspection shall be borne by the Contractor, and shall be paid promptly from time to time upon presentation of bills for same.

The Engineers shall have the right to take such samples of all materials as they consider necessary for testing or examination.

P. 35. *Final Inspection*

Before the completed work is accepted and paid for, the Contractor shall notify the Engineers in writing that it is ready for final inspection. Upon receipt of the notification, the Engineers will arrange to give the entire work a minute and thorough inspection, either in person or through a competent representative who has not been employed regularly on the special work. Any defects or omissions noted during this inspection must be made good by the Contractor without extra charge before the said work will be accepted or paid for in full.

P. 36. *Strictness of Inspection*

All materials and workmanship will be thoroughly and carefully inspected, and the Contractor will be held at all times to the spirit of the specifications; but nothing will be done by the Engineers or Inspectors to give the Contractor needless worry or annoyance, the intent of both specifications and inspection being simply to obtain work that will be first class in every particular and a credit to every one connected with its designing and construction.

P. 37. *Defective Work*

The Contractor, upon being so directed by the Engineers, shall remove, reconstruct, or make good, without charge, any work which the said Engineers may consider to be defectively executed. The fact that any defective material in the structure had been previously accepted by the

oversight of the Inspectors shall not be considered a valid reason for the Contractor's refusing to remove it or to make it good. And until such defective work is removed and made good, the Purchaser shall deduct from the partial payments or the final payment, as the case may be, whatever sum for defective work as may, in the opinion of the Engineers, be just and equitable.

P. 38. *Differences of Opinion*

If any differences arise between the Inspector and the Contractor regarding the meaning of these specifications and the accompanying plans, the Contractor shall bring the same immediately to the attention of the Engineers, who will adjust the said differences.

P. 39. *Position, Gradient, and Alignment*

The entire bridge must be constructed in the exact position required, the finished surfaces of tracks and floors must conform exactly to the elevations and gradient specified, and all parts of both substructure and superstructure must be in exact alignment and properly adjusted. The Contractor must provide all frames, forms, falsework, shoring, guides, and anchors that may be required to insure this result.

P. 40. *Other Contractors' Work*

Each contractor will be required to perform his work in the proper sequence in relation to other work, as may be directed by the Engineers, and properly to join his work to either existing or new construction.

P. 41. *Directions to Contractor*

All of the work is to be under the supervision of the Engineers, and they will give the Contractor directions and instructions from time to time; and all such directions are to be conformed to by the Contractor and by all of his employees and agents. In case that the Contractor shall not be present upon the work at any time when it may be necessary for the Engineers to give instructions, the foreman in charge shall receive and obey any orders that the Engineers may give. On the request of the Contractor or his representative any oral order given by the Engineers or their representatives will be repeated in writing. Subcontractors or agents of any kind of the Contractor are deemed employees of the Contractor, and they must conform to the directions and supervision of the Engineers in the same way as all other employees are required to conform.

P. 42. *Responsibility for Accidents*

The Contractor shall assume and be responsible for all accidents to men, animals, plant, and materials, due either directly or indirectly to

his operations, before the acceptance of the structure. The Contractor shall place sufficient and proper guards for the prevention of accidents, and shall put up and maintain at night suitable and sufficient lights.

P. 43. *Contractor's Risk*

The Contractor shall bear all loss or damage, from whatever cause arising, which may occur to the works or any portion of them, until the same are fully and finally completed and delivered to and accepted by the Purchaser; and if any such loss or damage occur before such final completion, delivery, and acceptance, the Contractor shall immediately, at his own expense, repair, restore, and re-execute the work so damaged, so that the whole work may be completed properly within the time limit.

P. 44. *Damages*

The Contractor shall indemnify and save harmless the Purchaser against all claims and demands of all parties whatsoever for damages or for compensation for injuries arising from any obstructions erected by the Contractor or his employees, or from any neglect or omission to provide proper lights and signals during the construction of the work.

P. 45. *Loading Metalwork on Cars and Shipping*

Projecting parts, liable to be bent or injured in transit, must be blocked with wood before shipment in such a way as to protect them from injury in handling or in transit. All small parts, such as rivets, bolts, nuts, washers, pins, fillers, and small connection plates, shall be boxed strongly; and the contents shall be marked plainly on each box, in addition to the shipping address. Small plates may be shipped in bundles, securely wired and properly tagged.

In shipping long plate-girders great care is to be taken to distribute the weight properly over the two cars that support them, and to provide means for permitting the cars to pass around curves without disturbing the loading.

In both the handling and shipment of metalwork every care is to be taken to avoid bending or overstressing the pieces or damaging the paint. All pieces bent or otherwise injured will be rejected.

P. 46. *Loading Metalwork on Vessel and Preparing Same Therefor*

Every piece, bundle, or package shall be carefully and plainly marked with the shipping address and destination, with the names and numbers of pieces, and with any other such marks of identification as may be necessary to ensure the correct disposition of the material. All small parts, such as rivets, bolts, nuts, washers, pins, fillers, and small connection plates, shall be boxed strongly, and the contents shall be marked

plainly on each box, in addition to the shipping address mentioned. All lateral angles shall be bolted together in pairs; and as many of such pairs shall be bundled together with clamps or wire as will be convenient for handling without injury in loading and unloading.

All pieces with open ends, such as truss members with forked ends, or laterals with unsupported plates or angles, or any other parts liable to injury in handling, shall have the ends packed with heavy blocks of timber, bolted thoroughly between the projections or to the body of the member in such a manner as to prevent any bending or other injury in handling or on shipboard. All portals or bracing frames shall be bolted together in pairs, or reinforced by timbers in such a manner as to prevent all possibility of injury in transportation.

All nuts on any rods or bolts shipped loose shall be screwed tightly in place, and the threads thereof shall be wound closely with twine so that the nuts cannot become loose and be lost off in handling, and so that the threads shall not be injured.

Especial care must be taken to have every part, piece, and package for each structure loaded in the same vessel. The parts of the different structures must be boxed separately and marked so that there can be no possibility of getting them confused or interchanged. As the omission of any part, however small, would cause great trouble and delay in the field, it is absolutely necessary to avoid any omissions.

The shipping invoices or lists are to be made to correspond to the bundles, boxes, and packages, so that each item on the list can be identified readily.

During both the loading on steamer and the unloading from same, especial care shall be taken to avoid injuring any of the metalwork; and the loading shall be so done as not to overstress any part and so as to prevent any shifting during the voyage. If, in spite of all precautions, some of the metalwork be injured, the entire expense to which the Purchaser is put because of such injury shall be borne by the Contractor.

All the expense involved by these special shipping and loading directions shall be borne by the Contractor, as no extra payment will be allowed therefor.

P. 47. *Demurrage and Cartage*

The contractor for the erection of the superstructure shall unload all superstructure materials promptly upon their arrival and transport them to the bridge site; and he shall be responsible for and shall pay any and all demurrage or other charges incurred by failure to unload cars or boats within the time alotted therefor by the transportation companies. He shall check against the shipping lists all parts and pieces of material as they are unloaded and shall properly report the same to the Engineers.

P. 48. *Loss of Metal and Other Materials*

If any metal or other material be lost or damaged in transit or during erection or at any time before the completion and final acceptance of the work, it shall be replaced at his own expense by the Contractor who is responsible for the materials when they are lost or damaged.

P. 49. *Contractor's Plant*

As soon as possible after the contract for the construction is signed, the Contractor, if so requested, is to prepare and submit to the Engineers for their approval a complete list of field plant, and is to indicate thereon which parts the Contractor already possesses and which he has yet to purchase. If the Engineers are not convinced that the proposed field plant is sufficient to complete the entire work properly and within the time limit set in the specifications, the Contractor must supplement the list as they may direct.

P. 50. *Notice of Commencement of Field Work*

For each bridge covered in the contract the Contractor shall give to the Purchaser formal written notice of his desire to begin field operations; and these shall not be started until proper written authority has been granted in answer to such notice.

P. 51. *Instrumental Work in Field*

The Contractor will be given bench-marks and points at various intervals throughout the structure; and he must provide his own men and instruments for determining alignment, elevations, and positions for all constructions between such points, subject to the check and corrections of the Engineers. In view of this understanding no excuse for delay will be considered because of alleged failure on the part of the Engineers to give the Contractor any information that could be obtained by instrumental work. Again, while the Engineers make the estimates of quantities of finished or partially finished constructions, they do not prepare nor even check the Contractor's bills of materials. Whenever the Engineers so request, the Contractor shall provide them, at his own expense, with intelligent workmen to aid in minor capacity in making measurements—for instance, in taping, rodding, picketing, setting points, stakes, and targets, and such like work.

P. 52. *Engineers' Field Office*

The Contractor shall provide at his own expense **for each structure,** at some place convenient to the work at the bridge site, a comfortable and

sufficiently commodious office, to be used solely by the Engineers during the entire construction of the **said** structure. The location of the said office **in each case** is to be determined by the Engineers; and the character of the building provided must meet with their approval, it being understood that serviceable, but not elaborate nor expensive, construction will be demanded. The said office building shall remain the property of the Contractor after the completion of the structure.

P. 53. *Arch Centres, Forms, Staging, Runways, and Falsework*

The Contractor shall furnish all **arch centres,** forms, staging, runways, and falsework; and there shall be no direct payment therefor, unless there be made properly in writing a special agreement to the contrary. The Contractor shall build all falsework and staging of adequate strength to support safely the loads imposed upon them without injurious deformation or settlement.

The Contractor shall provide suitable forms, and their design shall be adapted to the structure and to the kind of surface required on the concrete. The forms for concrete surfaces which will be exposed to view shall be made of lumber which is dressed on both edges * and on the faces next to the concrete, and the pieces shall be straight so as to insure a tight form that will prevent the leakage of mortar. Forms shall be substantially built and supported in such a manner as to prevent bulging or deformation from the weight or ramming of the concrete. All exposed corners and edges of concrete construction are to be rounded off to a two-inch radius, or as shown on the drawings.

Before the removal of forms the concrete shall have attained a strength which, in the opinion of the Engineers, will prevent injury from such removal. Falsework shall be maintained under all constructions until such time as the concrete is able to sustain both itself and any load that is likely to come upon it with absolute safety to the concrete.

Although the designs for all forms, staging, falsework, and arch centres are to be prepared by the Contractor, they are to be submitted to the Engineers for their approval before being used.

In all cases the Contractor is to be responsible for and must make good any injury arising from inadequate forms or falsework, or from the premature removal thereof.

I. 54. *Removal of Débris*

Upon the completion of his contract **the (or each)** Contractor shall remove all surplus material, temporary structures, and débris resulting from his operations **in new construction, reconstruction, or removal of old**

*** For the very best results the use of tongued-and-grooved lumber or ship-lap is advisable.**

structures; and he shall leave the premises in a neat, orderly condition. Falsework timbers and piles are to be removed to the level of the ground, or the level of the river bed, or as directed by the Engineers. The river and channel must be cleared of all piles, falsework, and débris to the satisfaction and acceptance of ....; and such acceptance must be secured in writing by the Contractor before withdrawing his equipment from the site.

P. 55. *Metal*

Unless otherwise specified all metal shall be medium steel. Rivets and bolts shall be made of soft steel; rolled shafts and pins of machinery steel; pinions and other forgings of the steel hereinafter specified for forgings; bushings of bronze, unless otherwise specified; washers for timber bearings of malleable iron; and all other castings of cast steel, unless otherwise specified. For special conditions nickel steel or other alloy may be used. Cast iron shall not be employed in bridges, excepting for thick base plates and lamp-posts, or unless special written permission or instructions to do so be given by the Engineers.

P. 56. *Requirements for Carbon Steel*

All steel shall be manufactured by the open-hearth process and shall conform to the following requirements:

The phosphorus and sulphur must not exceed the percentages given in the following table:

Impurity	Soft Steel	Medium Steel	Machinery Steel	Cast Steel	Forged Steel
Phosphorus—Basic steel...	0.04	0.04	0.04	0.05	0.05
Phosphorus—Acid steel...	0.04	0.06	0.06	0.08	0.05
Sulphur................	0.04	0.05	0.05	0.05	0.05

These values are for analyses on test ingots taken during the pouring of the melts as well as for check analyses on the finished product in the case of machinery steel and forged steel. For check analyses made from finished material an increase in these values of twenty-five (25) per cent will be allowed.

The ultimate tensile strength per square inch shall fall within the following limits:

Rivet steel........................	46,000 lbs. to 54,000 lbs.
Medium steel......................	60,000 lbs. to 70,000 lbs.
Machinery steel....................	70,000 lbs. to 80,000 lbs.
Cast steel.........................	Not less than 70,000 lbs.
Forged steel.......................	Not less than 80,000 lbs.

The elastic limit, as determined by the drop of the beam, shall be not less than fifty (50) per cent of the ultimate tensile strength.

For rivet steel and medium steel the percentage of elongation in eight inches, as determined on the test specimens, shall be not less than 1,500,000 divided by the ultimate tensile strength, except that for material less than five-sixteenths ($\frac{5}{16}$) inch and more than three-quarters ($\frac{3}{4}$) of an inch in thickness the following modifications will be allowed:

a. For each one-sixteenth ($\frac{1}{16}$) inch in thickness below five-sixteenths ($\frac{5}{16}$) inch a deduction of two and one-half ($2\frac{1}{2}$) will be allowed from the specified percentage.

b. For each one-eighth ($\frac{1}{8}$) inch in thickness above three-quarters ($\frac{3}{4}$) of an inch a deduction of unity will be allowed from the specified percentage.

c. For pins and rollers over three (3) inches in diameter a deduction of five (5) will be allowed from the specified percentage.

For machinery steel and cast steel the elongation in two (2) inches shall be not less than eighteen (18) per cent, and for forged steel not less than twenty-two (22) per cent, as determined on the test specimens.

The reduction of area for cast steel shall not be less than twenty-five (25) per cent, for forged steel not less than thirty-three (33) per cent, and for machinery steel not less than thirty-five (35) per cent, as determined on the test specimens.

In the case of small or unimportant castings, a test to destruction on three castings from a lot may be substituted for the tension and bending tests. This test shall show the material to be ductile, free from injurious defects, and suitable for the purpose intended. A lot shall consist of all castings from one melt in the same annealing charge.

V. 57. *Requirements for Nickel Steel*

The requirements for nickel steel have not reached the same stage of perfection as have those for carbon steel. The American Society for Testing Materials has adopted a very good set of specifications for nickel steel, but the author is assured that a better quality than therein prescribed can be obtained from the Manufacturers. Elastic limits of 55,000 and, possibly, 60,000 pounds per square inch for structural shapes can be secured. This will cost slightly more per pound for the rolled material, but less *in toto* for the finished structure. However, it has been necessary, so far, to take up each case with the Manufacturers as it arises and arrange for the qualities of the steel at such a time. This procedure will be necessary until nickel steel is more generally used and until the better grades are easily procurable.

P. 58. *Identification of Metal*

Each ingot shall be stamped or marked plainly with its proper melt number; and this melt number must be stamped or painted plainly on

all blooms, billets, or slabs made from such ingots, in order to identify the material throughout its various processes of manufacture; and the melt number must be stamped plainly on each piece of finished material Rivet and lacing steel and small pieces for pin-plates and stiffeners may be shipped in bundles, securely wired together, with the blow or melt number on a metal tag attached thereto.

P. 59. *Methods of Testing of Steel*

The chemical determinations of the percentages of carbon, phosphorus, sulphur, and manganese shall be made by the Manufacturer from a test ingot taken at the time of the pouring of each melt of steel, and a correct copy of such analysis shall be furnished to the Engineers. Check analyses shall be made from finished material representing each melt, if called for

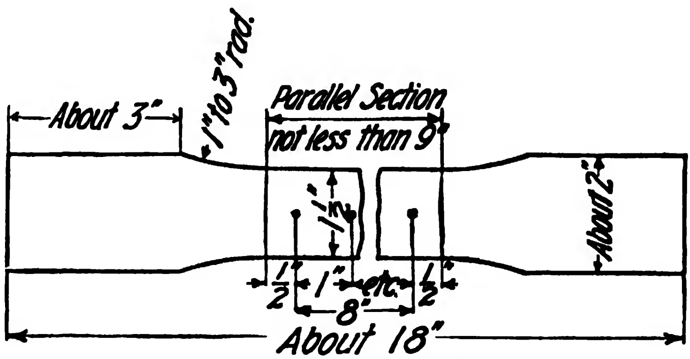

FIG. 79a. Tensile Test Specimen.

by the Engineers. For rollers, pins, and shafts, the drillings for a check analysis shall be taken at any point midway between the centre and the surface of the roller, pin, or shaft, or from a full-sized projection thereof; or turnings may be taken from a test specimen. For cast steel the drillings shall be taken not less than one-quarter (¼) inch beneath the surface of the casting.

The tensile strength, elastic limit, elongation, and reduction of area of plates, shapes, and bars shall be determined by loading to a point of rupture a specimen machined to the form and dimensions shown in Fig. 79a, in which the thickness of the test specimen shall be that of the finished material, except that for plates and eye-bar flats over one and one-half (1½) inches in thickness the specimen may be machined to a thickness or diameter of at least three-quarters (¾) of an inch for a length of at least nine (9) inches. For pins, rollers, and bars (except eye-bar flats) over one and one-half (1½) inches in thickness, and for forgings, castings, and shafts and pins of machinery steel, the test specimens shall be of the

form and dimensions shown in Fig. 79*b*. Test specimens of rivet steel shall be of the full section of rods as rolled.

Specimens for bending tests shall be similar in outline to those used in tension tests for plates, shapes, bars, and rivets, except that test specimens for eye-bar flats shall always have a thickness equal to the thickness of the finished bar. Bending-test specimens for pins, rollers, and bars (except for eye-bar flats), and for forgings, castings, and shafts and pins of machinery steel, shall be one (1) inch by one-half (½) inch in section.

Test specimens shall be taken from rolled steel in the condition in which it comes from the rolls, except as noted above for plates and eye-bar flats over one and one-half (1½) inches thick, and for pins and rollers, in which cases the axis of the specimen shall be located at any point midway between the centre and the surface and shall be parallel to the axis of the bar. The test specimen shall be taken from the bar itself or

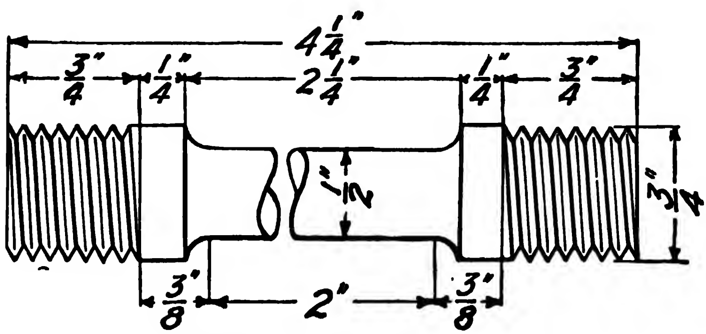

Fig. 79*b*. Tensile Test Specimen.

from a full-sized extension of the bar. For pins and shafts of machinery steel and for forgings the specimen shall be taken from the piece itself or from a full-sized prolongation of the same parallel to its axis. It shall be taken midway between the centre and surface and shall be cut parallel to the axis of the piece. For cast steel the test specimens shall be cut from coupons moulded and cast on some portion of one or more castings from each melt or from sink heads, if the heads are of sufficient size. If the castings weigh less than five hundred (500) pounds, or are of such design that coupons cannot be attached, two test bars shall be cast to represent each melt; or the quality of the castings shall be determined by tests to destruction as hereinbefore specified.

Every melt from which material is furnished must be represented by the tests, and the test specimens shall be cut by the mill from finished material so selected by the Inspector that the different sizes and shapes in the order shall be as well represented as possible. Material which is to be used without annealing or further treatment shall be tested in the condition in which it comes from the rolls. When material is to be annealed or otherwise treated for use, the test specimens representing such

material shall undergo the same treatment as the pieces from which they are cut.

P. 60. *Number of Test Pieces of Steel*

At least two tensile tests and two bending tests shall be made on specimens from different ingots of each melt, except in the case of small melts for which the number may be reduced to one. A bending test shall be made with each tensile test, if required; and, if desired, it may be made on the broken test pieces of the tensile tests.

If material for various shapes is to be rolled from the same melt, the specimens for testing are to be so selected as to represent the different shapes rolled from such melt. Lots for testing shall not exceed twenty (20) tons in weight; and plates rolled in universal mills or in grooves shall constitute a separate lot, as shall also sheared plates, angles, channels, or beams. Each melt, however, must be considered as a special lot and tested accordingly.

The number of tests of steel castings will depend upon the character and importance of the said castings, but each annealing charge as well as each melt must be represented by a test.

For forgings at least one test specimen shall be prepared for each ten forgings of each kind; but not less than two specimens shall be made for any single kind of forging. Each annealing charge, as well as each melt, must be represented by a test.

If any test specimen shows defective machining or develops flaws, it may be discarded and another specimen substituted.

If the percentage of elongation of any tension test specimen is less than that specified and if any part of the fracture is more than three-quarters (¾) of an inch from the centre of the gauge length of a 2-inch specimen or is outside of the middle third of the gauge length of an 8-inch specimen, a retest will be allowed.

The Inspector will be permitted considerable latitude in respect to the number of tests required, reducing it when the metal runs uniformly and increasing it when it does not.

P. 61. *Bending Tests for Steel*

Specimens of medium steel cut from plates, shapes, and bars shall bend cold through 180 degrees without cracking on the outside of the bent portion, as follows: For material three-quarters (¾) of an inch or under in thickness, flat on itself; for material over three-quarters (¾) of an inch to and including one and one-quarter (1¼) inches in thickness, around a pin the diameter of which is equal to the thickness of the specimen; and for material over one and one-quarter (1¼) inches in thickness, around a pin the diameter of which is equal to twice the thickness of the test specimen.

Angles three-quarters (¾) of an inch and less in thickness shall open flat, and angles one-half (½) inch and less in thickness shall bend shut, cold, under blows of a hammer, without sign of a fracture. This test shall be made only when required by the Inspector.

Specimens for eye-bar flats shall bend cold through 180 degrees without cracking on the outside of the bent portion as follows: For material three-quarters (¾) of an inch or under in thickness, around a pin the diameter of which is equal to the thickness of the specimen; for material over three-quarters (¾) of an inch to and including one and one-quarter (1¼) inches in thickness, around a pin the diameter of which is equal to twice the thickness of the specimen; and for material over one and one-quarter (1¼) inches in thickness, around a pin the diameter of which is equal to three times the thickness of the specimen.

Test specimens of pins, rollers, and other bars of medium steel shall bend cold through 180 degrees around a one-inch pin without cracking on the outside of the bent portion.

Test specimens of rivet steel shall bend cold through 180 degrees flat on themselves without cracking on the outside of the bent portion, and nickel steel specimens, bent 180 degrees around a pin the diameter of which is the same as that of the specimen, shall not break with an abrupt, square fracture, but shall show a gradual break and a fine, silky, homogeneous fracture.

Test specimens of machinery steel and forged steel shall bend cold through 180 degrees around a one-inch pin without cracking on the outside of the bent portion.

Test specimens for cast steel shall bend cold through 90 degrees around a one-inch pin without cracking on the outside of the bent portion.

P. 62. *Drifting Tests for Steel*

Medium steel shall be so ductile that the drifting of rivet holes, punched within two (2) inches of a sheared edge, till their diameters are increased fifty (50) per cent, shall not crack the metal. Machinery steel shall not crack, when similarly tested, till the rivet hole is increased twenty-five (25) per cent in diameter.

P. 63. *Fracture of Steel*

All carbon steel broken test pieces of rolled material and all broken eye-bars must show a silky fracture of uniform color. Cast steel may show a fine granular fracture.

P. 64. *Tests of Full-Sized Eye-Bars*

Full-sized eye-bars may be tested to destruction, provided notice be given in advance of the number and size required for this purpose, so

that the material may be rolled at the same time as that required for the structure. The number of tests of full-sized eye-bars will depend upon the size of the order and upon the regularity of the results of the tests. In general, for small orders, the number of tests shall be about three (3) per cent of the number of eye-bars in the order, but never less than two (2) bars for an order for a single span. For large orders the number of tests shall be about two (2) per cent of the number of eye-bars in the order. Should the Inspector find the bars to be very uniform in strength, elasticity, and ductility, and fully up to the specifications, he shall be at liberty to reduce the number of tests of full-sized bars. In the case of testing long bars, it will be allowable to choose a bar at random from a number of finished bars, cut it in two, and upset the end of each piece, thus making two test-bars.

Full-sized bars of medium carbon steel must show an ultimate tensile strength of at least fifty-six thousand (56,000) pounds per square inch. The elongation shall not be less than fourteen (14) per cent in a gauged length of ten (10) feet; and the elastic limit shall not be less than fifty (50) per cent of the ultimate strength of the bar. Any lot of steel bars which meets the preceding requirements shall be accepted, if none of the bars which break in the eye show an ultimate strength, elastic limit, or elongation less than that specified for the body of the bar, unless one-fourth (¼) of the full-sized samples so tested break in the eye. In case of failure to meet any of these requirements, the lot from which the sample bars were taken shall be rejected. All full-sized sample bars which break at less than the ultimate strength specified, or which do not otherwise fill the specifications, shall be at the expense of the Contractor; unless, in case of those that break in the eye, he shall have made objection in writing to the form or dimensions of the heads before manufacturing the eye-bars. All others shall be paid for by the Purchaser at the contract price of finished metalwork on cars at shops, less the scrap value of the broken bars.

P. 65. *Tests of Full-Sized Built Members or Details*

In addition to the specimen tests and eye-bar tests hereinbefore described, the Contractor may be required to make, at his own expense, under the direction of the Engineers or of their Inspector, any tests of full-sized members or details that the Engineers may prescribe, provided that the said members or details are similar to those used on the work, and provided that the total cost to the Contractor of such extra tests does not exceed one-quarter (¼) of one per cent of the total contract price of the work.

P. 66. *Finish of Rolled Steel*

All finished steel as it comes from the rolls shall be free from seams, cracks, and flaws of all kinds, and shall be smooth and clean in finish.

P. 67. *Plates*

Plates rolled on the universal mill may be made from slab ingots, but all other plates shall be formed from slabs made by rolling an ingot and cutting off the scrap. The ingot shall have at least twice the cross-sectional area of the slabs made from it, and the slabs shall be at least six times as thick as the plates made from them.

P. 68. *Forgings*

Forgings shall be free from cracks, flaws, seams, or other injurious imperfections, shall conform to the dimensions shown on the drawings, and shall be made and finished in a workmanlike manner. All forgings shall be annealed. No forging shall be done at less than red heat.

P. 69. *Steel Castings*

Steel castings shall be free from injurious blow-holes, true to pattern, and of workmanlike finish, all corners being properly filleted. All steel castings shall be thoroughly annealed, sufficient time being taken to ensure annealing throughout.

When the bearing surface of any steel casting is finished, there shall be no blow-holes visible exceeding one (1) inch in either dimension, nor exceeding one-half ($\frac{1}{2}$) square inch in area. The length of blow-holes cut by any straight line laid in any direction shall never exceed one inch in any one foot.

The correction of defects in castings by welding electrically, by thermit, or by similar processes will not be permitted.

P. 70. *Iron Castings*

Except where chilled iron is specified, all iron castings shall be of tough gray iron, with not more than 0.10 per cent sulphur. They shall be true to pattern, out of wind, and free from flaws and excessive shrinkage. They shall be substantially of the thicknesses required by the plans, and they shall have sharp and clean angles, lines, and mouldings and filleted corners.

Tests shall be made on a round bar one and one-quarter ($1\frac{1}{4}$) inch in diameter and 15 inches long. The transverse test shall be made on a length of 12 inches with a load at the middle. The minimum breaking load so applied shall be 2,900 pounds, with deflection of at least one-tenth ($^1/_{10}$) inch before rupture.

P. 71. *Bronze Bushings*

For low-unit pressures on journal bearings and where the speed is high, all bushings shall be composed of phosphor bronze of the following composition:

Copper	79.7 per cent
Tin	10.0 per cent
Lead	9.5 per cent
Phosphorus	0.8 per cent

The amount of tin shall not be less than nine (9) per cent nor more than eleven (11) per cent. The amount of lead shall not be less than eight (8) per cent nor more than eleven (11) per cent. The amount of phosphorus shall not be less than seven-tenths (7/10) nor more than one (1) per cent. The amount of ingredients other than copper, tin, lead and phosphorus shall not exceed one-half (½) of one per cent.

Specimen tests of the alloy must give the following physical results:

Compression

Elastic limit in pounds per square inch	13,000 to 15,000
Permanent set in inches from a load of 100,000 pounds per square inch	0.27

The elastic limit is based on a set of 0.001 inch in one (1) inch.

Tension

Yield point in pounds per square inch	20,000
Ultimate strength in pounds per square inch	25,000
Elongation, percentage in two inches	4
Reduction of area, per cent	3

For high unit pressures on journal bearings and where the speed is low, and for centre disks of centre-bearing swing-spans, the bushing metal shall be of the following composition:

Copper	85.2 per cent
Tin	14.0 per cent
Phosphorus	0.8 per cent

The amount of tin shall not be less than thirteen (13) per cent nor more than fifteen (15) per cent. The amount of phosphorus shall not be less than seven-tenths (7/10) per cent nor more than one per cent. The amount of ingredients other than copper, tin, and phosphorus shall not exceed one-half (½) of one per cent.

The approximate physical results from this composition on a cylinder with an area of one (1) square inch and one (1) inch long shall be:

Compression

Elastic limit in pounds per square inch	20,000 to 22,000
Permanent set in inches from a load of 100,000 pounds per square inch	0.12 to 0.16

The elastic limit is based on a set of 0.001 inch in one (1) inch.

P. 72. *Babbitt Metal*

Babbitt metal shall have the following composition:

Tin, two (2) parts; zinc, one (1) part; and to this must be added antimony to the amount of five (5) per cent of the total weight of the tin and zinc.

P. 73. *Pins and Shafts*

Pins and shafts up to four (4) inches in diameter, unless otherwise specified, may be rolled; those of greater diameter shall be forged. The rounds from which the pins and shafts are to be turned must be true, straight, and free from all injurious flaws or cracks. All forged pins and shafts shall be reduced to size from a single bloom or ingot until perfect homogeneity is secured throughout the whole mass. The blooms or ingots shall have at least three times the cross-sectional area of the finished pins or shafts made from them. No forging shall be done at less than red heat.

All pins and shafts shall be turned accurately to a gauge, and shall be finished perfectly round, smooth, and straight. All pins up to six (6) inches in diameter shall fit the pin holes within one-fiftieth ($\frac{1}{50}$) of an inch; and all pins over six (6) inches in diameter shall fit their holes within one-thirty-second ($\frac{1}{32}$) of an inch.

The Contractor shall provide a sufficient number of pilot nuts for each size of pin to preserve the threads while the pins are being driven.

P. 74. *Reinforcing Bars*

All bars for reinforcing shall be deformed bars having lugs, corrugations, or other deformations which present to the concrete a positive shoulder having an angle of not less than forty-five (45) degrees with the axis of the bar. Bars with deep corrugations liable to form air-pockets or with deformations having a wedging action tending to split the concrete will not be accepted. All reinforcing material shall be rolled from billets and shall be of medium steel, uniform in character, and manufactured by the open-hearth process. Any attempt to substitute steel manufactured by the Bessemer process, or from old steel rails, will be considered a violation of the contract and adequate reason for its cancellation. All finished material as it comes from the mills shall be free from all flaws, cracks, or other defects, and must have a clean finish.

P. 75. *Permissible Variations in Weight and Gauge*

The cross-section or weight of each piece of steel shall not vary more than 2.5 per cent from that specified, except in the case of sheared plates,

which shall be covered by the following permissible variations to apply to single plates:

(*a*) *When Ordered to Weight.*—

For plates 12½ lbs. per sq. ft. or over:

Under 100 in. in width, 2.5 per cent above or below the specified weight;

100 in. in width or over, 5 per cent above or below the specified weight.

For plates under 12½ lbs. per sq. ft.:

Under 75 in. in width, 2.5 per cent above or below the specified weight;

75 to 99 in., inclusive, in width, 5 per cent above or 3 per cent below the specified weight;

100 in. in width or over, 10 per cent above or 3 per cent below the specified weight.

(*b*) *When Ordered to Gauge.*—The thickness of each plate shall not vary more than 0.01 in. under that ordered.

An excess over the nominal weight corresponding to the dimensions on the order shall be allowed for each plate, of not more than that shown in the following table, one (1) cubic inch of rolled steel being assumed to weigh 0.2833 lb.:

Thickness Ordered, in.	Nominal Weight, Lbs. per Sq. Ft.	Allowable Excess (Expressed as Percentage of Nominal Weight). For Width of Plate as Follows:						
		Under 50 in.	50 to 69 in. Incl.	70 in. or Over	Under 75 in.	75 to 99 in. Incl.	100 to 114 in. Incl.	115 in. or Over
$\frac{1}{8}$ to $\frac{5}{32}$	5.10 to 6.37	10	15	20	...	...	...	...
$\frac{5}{32}$ " $\frac{3}{16}$	6.37 " 7.65	8.5	12.5	17	...	...	...	...
$\frac{3}{16}$ " $\frac{1}{4}$	7.65 " 10.20	7	10	15	...	...	...	...
$\frac{1}{4}$	10.20	...	...	..	10	14	18	...
$\frac{5}{16}$	12.75	...	...	..	8	12	16	...
$\frac{3}{8}$	15.30	...	...	..	7	10	13	17
$\frac{7}{16}$	17.85	...	...	..	6	8	10	13
$\frac{1}{2}$	20.40	...	...	..	5	7	9	12
$\frac{9}{16}$	22.95	...	...	..	4.5	6.5	8.5	11
$\frac{5}{8}$	25.50	...	...	..	4	6	8	10
over $\frac{5}{8}$	.....	...	...	..	3.5	5	6.5	9

P. 76. *Sheared Edges*

All sheared and hot-cut edges shall have not less than one-quarter (¼) inch of metal removed by planing to a smooth, finished surface. Lacing-bars, fillers, stay-plates, lateral-bracing connecting plates, and top and bottom edges of plate-girder webs only will be exempt from this requirement. No sharp or unfilleted re-entrant corners will be allowed anywhere in the work.

P. 77. *Drifting*

No drifting to distort the metal will be allowed. If a hole must be enlarged to admit a rivet it must be reamed.

P. 78. *Straightening*

All material must be thoroughly straightened before being laid off or worked in any way.

P. 79. *Annealing*

In all cases where a steel piece, in which the full strength is required, has been partially heated or bent, the whole piece must be subsequently annealed. In pieces of secondary importance where the bending is slight, the said bending is to be done cold, and no annealing in such cases will be called for. Crimped web-stiffeners will not need annealing.

P. 80. *Rivet Holes*

Rivet holes must be accurately spaced; the use of drift pins will be allowed only for bringing together the several parts forming a member, and they must not be driven with such force as to distort the metal about the holes. The distance between the edge of any piece and the centre of a rivet hole must never be less than one and a half (1½) inches, excepting for lattice bars, small angles, and where especially shown otherwise on the Engineers' drawings; and wherever practicable this distance shall be at least twice the diameter of the rivet.

P. 81. *Rivets*

Rivets when driven must completely fill the holes, and must have full heads concentric with the rivet holes. Shop rivets must be driven, whenever practicable, by a machine capable of retaining the applied pressure after the upsetting is completed. Elsewhere the pneumatic hammer shall be used if possible. The rivet heads must be full and neatly finished, of approved hemispherical shape, in full contact with the surface, or be counter-sunk when so required, and of a uniform size for the same sized rivets throughout the work; and they must pinch the connected pieces thoroughly together. Flattened heads may be used in certain places, if necessary for clearance. Except where shown otherwise on the drawings, all rivet diameters are to be seven-eighths (⅞) of an inch. No loose or imperfect rivets will be allowed to remain in any part of the metalwork.

When rivets have a grip exceeding four (4) inches they are to be tapered, the amount of total taper varying from one-sixteenth ($^1/_{16}$) to three-sixteenths ($^3/_{16}$) of an inch according to the length of grip. All long rivets are to have their points cooled slightly by dipping them in water.

In driving extra-long rivets it is necessary to apply a pneumatic hammer at each end of the rivet.

P. 82. *Field Riveting*

All field rivets are to be driven by pneumatic hammers of type and size to be approved by the Engineers. The shanks of the rivets must be of uniform circular section throughout (excepting in the case of unusually long rivets, which must be tapered and cut square at end); and they must be free from projections or other imperfections which would prevent the head from fitting closely before the rivet is driven.

The **Manufacturer of the Metalwork*** is to provide a complete equipment of field rivets, with an excess allowance for waste for each kind of rivet used equal to fifteen (15) per cent of the number theoretically called for plus ten (10); and **the Erecting Contractor**† will be required to furnish at his own expense any rivets above that excess which may be needed.

P. 83. *Sub-Punching and Reaming*

All rivet holes in steel work, if punched, shall be made with a punch three-sixteenths ($^3/_{16}$) of an inch in diameter less than the diameter of the rivet intended to be used, and they shall be reamed to a diameter one-sixteenth ($^1/_{16}$) inch greater than that of the said rivet.

All the pieces to be riveted together shall be assembled and bolted together before the reaming is done; for the principal objects of sub-punching and reaming are to insure the correct matching of rivet holes and the avoidance of holes of excessive diameter, as well as the removal of most, if not all, of the incipient cracks started by the punching. All reaming is to be done by means of twist-drills, the use of tapered reamers being prohibited except where twist-reamers cannot be employed. All holes must be at right angles to surface of member, and all sharp or raised edges of holes under heads must be slightly rounded off before the rivets are driven. All holes for field rivets, excepting those for lateral and sway-bracing, when not drilled to an iron templet, shall be reamed while the connecting parts are temporarily assembled.

Punching shall not be permitted in any piece in which the thickness of the metal exceeds the diameter of the cold rivet that is to be used; but all such pieces shall be drilled.

Holes in lattice bars and batten plates may be punched full-size.

All punched work shall be so accurately done that after the various component pieces are assembled and before the reaming is commenced, forty (40) per cent of the holes can be entered easily by a rod of a diameter one-sixteenth ($^1/_{16}$) of an inch less than that of the punched holes;

* Replace by *Contractor* if the Manufacturer erects.

† Replace by *he* if the Manufacturer erects.

eighty (80) per cent by a rod of a diameter one-eighth ($\frac{1}{8}$) of an inch less than same; and one hundred (100) per cent by a rod of a diameter one-quarter ($\frac{1}{4}$) of an inch less than same. Any shopwork not coming up to this requirement will be subject to rejection by the Inspector.

Graphite shall, preferably, be the lubricant for reaming; but oil may be used, if desired. The Contractor will not be allowed to employ soapsuds without special permission from the Engineer.

P. 84. *Reaming Connections*

Wherever practicable, reaming must be done after all the pieces which are to be fastened together by the same rivets have been assembled. If necessary to take the pieces apart for shipping or handling, the respective pieces reamed together must be so marked that they may be reassembled in the final setting up. No interchanging of pieces after reaming will be allowed.

All riveted trusses and all towers for movable bridges shall be assembled and drilled or reamed in the shop.

All spliced members shall be put together in the shop, and the field rivet holes therefor shall be reamed to a fit while these members with their splice plates are in place. All spliced chord sections or columns must be assembled and strung out in the shop in lengths of not less than three sections, and after being drawn into contact at the joints and lined up perfectly with splice plates in place, the field rivet holes shall be reamed to a fit before taking apart, and the assembled parts with their splice plates shall be match-marked so that they may be reassembled in the final setting up.

All field connections in the floor system must be reamed to a fit either while the members are assembled in the shop, or by using an accurate steel or cast iron templet not less than one inch thick.

P. 85. *Marking and Match-Marking*

All members shall be plainly and well marked in accordance with the erection diagram, and all members assembled for reaming or drilling shall be match-marked so that they may be readily assorted and reassembled in the field.

P. 86. *Milling Beams and Stringers*

The floor-beams must be milled on both ends to correct length after the end connection angles are in place, and the said end connection angles must be so accurately fitted that not more than one-sixteenth ($\frac{1}{16}$) of an inch will be taken off them at their roots. The abutting ends of cantilever beams must be milled in the same manner.

The end connection angles of stringers are to be riveted to the webs

with the whole stringer assembled in an iron frame which will give the exactly correct length of stringer and the correct position of the angles.

P. 87. *Built Members*

Built members must, when finished, be true and free from twists, kinks, buckles, or open joints between the component pieces. All abutting surfaces of compression members must be planed or turned to even bearings so that they shall be in as perfect contact throughout as can be obtained by such means; and all such finished surfaces must be protected by white lead and tallow before shipment from the shop.

The ends of all webs and of chord or flange angles that abut against other webs must be faced true and square or to exact bevel; and the end stiffeners must be placed perfectly flush with these planed ends, so as to afford a proper bearing. Filling plates beneath end stiffening angles must be practically flush with the said angles, and must in no case project outside of same at the bearings. All stiffeners must have a tight, driving fit at both upper and lower flanges of girders. No web plate will be allowed to project beyond the flange angles or to recede more than one-eighth (⅛) of an inch from faces of same.

All filling and splice plates in riveted work must fit at their ends to the flanges sufficiently close to be sealed by the paint against the admission of water; but they need not be tool finished, unless so specially indicated either on the drawings or in the specifications. Edges of spliced web plates must be faced so as to provide close contact throughout the entire depth, unless special written permission to the contrary be given.

P. 88. *Limits of Error in Structural Steel*

No piece having an error of one-thirty-second ($\frac{1}{32}$) of an inch between centres of pin-holes, or one-fiftieth ($\frac{1}{50}$) of an inch in the diameter of the pin or its hole, will be accepted.

P. 89. *Camber*

Truss spans shall be cambered as noted on the drawings. Plate-girder spans need not be cambered.

P. 90. *Correction of Secondary Stresses*

The secondary stresses in riveted trusses are to be modified by lengthening and shortening the various truss members the amounts of their respective shortening and lengthening under dead load plus one-half the live-plus-impact load, drilling or reaming the chord splices while the chords are assembled in straight lines, then forcing the truss members into their proper positions for connection to each other before drilling or reaming the holes in the joints.

P. 91. *Eye-Bars*

Except in the case of loop-eyes, no weld will be allowed in the body of the eye-bar. The heads of the eye-bars shall be made by upsetting, rolling, or forging into shape. A variation from the specified dimensions of the heads will be allowed, in thickness of one-thirty-second ($^1/_{32}$) of an inch below and one-sixteenth ($^1/_{16}$) of an inch above that specified, and in diameter of one-fourth ($^1/_4$) of an inch in either direction. Eye-bars must be perfectly straight before boring.

P. 92. *Pin-Holes*

All pin-holes must be bored truly parallel and at right angles to the axis of the member, unless otherwise shown on the drawings; and in pieces not adjustable for length, no variation of more than one-thirty-second ($^1/_{32}$) of an inch will be allowed in length between centres of pinholes.

P. 93. *Turned Bolts*

When members are connected by bolts which transmit shearing-stresses, the holes must be reamed parallel, and the bolts must be turned to a driving fit. The threaded portions of turned bolts shall be one-eighth ($^1/_8$) of an inch less in diameter at root of thread than the body of the bolt.

P. 94. *Turnbuckles, Nuts, Threads, and Washers*

All sleeve-nuts, turnbuckles, and clevises must be made so strong and stiff that they will be able to resist without rupture the ultimate pull of the members which they connect, and without distortion the greatest twisting moment to which they could ever be subjected. They must be made so that the threaded lengths of the rods engaged can be verified.

The dimensions of all square and hexagonal nuts, except those on the ends of pins, shall be such as to develop the full strength of the body of the adjustable member. No round-headed bolts will be allowed unless specially indicated on the drawings.

Washers must be used under the heads of all timber bolts when the bearing is on the wood, and all washers and nuts must have uniform bearing. All washers are to be made of malleable iron of good quality, and they must be sufficiently large and thick to provide properly for distributing the pressure due to the greatest allowable tension in the bolt over the area of the washer. They must be finished in a neat and workmanlike manner and must be free from all defects.

All threads, except those on the ends of pins, must be of the United States standard. Each adjustable nut must be provided with an effective nut-lock or check-washer.

P. 95. *Rollers*

Round rollers and the rolling surfaces of segmental rollers shall be accurately turned to a gauge, and must be finished perfectly round and to the correct diameter or diameters, from end to end. The sides of segmental rollers need not be finished, but they must be forged straight and true. The tongues and grooves in plates and rollers must fit snugly, so as to prevent lateral motion. Roller-beds and shoes must be planed.

P. 96. *Anchor Bolts*

All bed plates and bearings must be bolted to the masonry either by fox bolts or by bolts set in the masonry during its construction. In the case of fox-bolting, the Contractor **for Erection** must drill all holes and set the bolts to place with Portland cement grouting. All anchor bolts shall be of soft steel with United States standard threads. The lengths of the nuts for all anchor bolts shall be equal to or greater than the diameter of the bolt. Anchor bolts are not to be painted before shipment; but the exposed portions thereof, after erection, shall receive two (2) coats of paint when the other metalwork is painted.

P. 97. *Steel Hand-Rails*

Hand-rails,* **as shown on the accompanying drawings, are to be furnished by the Manufacturer of the Metalwork and put in place by the Contractor for Erection. They** are to be laid and firmly attached truly to line and elevation from end to end of structure. Any sliding joints provided are to be made perfectly operative. The entire hand-railing is to be finished to the satisfaction of the Engineers.

P. 98. *Name-Plates, Patent-Plates, and Year-Plates*

Name-plates, patent-plates, and year-plates of design to be prepared by the Engineers shall be furnished and attached in the various places and in the manner required by the Engineers. They shall be of **cast iron or bronze,** as specified on the drawings.

I. 99. *Steel Tapes*

The Contractor who furnishes the metalwork shall, immediately after the execution of his contract, furnish the Purchaser, free from charge, one steel tape fifty (50) feet long, and another .... (......) feet long, both guaranteed to agree exactly with the shop standards of the manufacturer of the metalwork.

* Omit portion in bold face type if the Manufacturer is to erect.

V. 100. *Machinery in General*

The first part of the example given will suffice for this clause for movable bridges in general except where such additional requirements are deemed advisable as given for swing spans.

Example

Unless otherwise indicated on the drawings, all cast portions of the machinery shall be made of cast steel, all rolled shafts and pins shall be made of machinery steel, and all forgings shall be made of forged steel. The machinery shall be finished and machined according to the best machine shop practice and to the satisfaction of the Engineers; and the limits of accuracy which the Contractor desires to observe in machining the work and the allowances for taper-shrinkage or pressed fits shall be placed on the Contractor's working drawings, but the approval of the said drawings by the Engineers shall not relieve the Contractor from full responsibility for the satisfactory construction and operation of the machinery. All machinery shall be satisfactory to the Engineers, and the Contractor shall furnish the Purchaser with a guarantee (satisfactory to the Purchaser) to replace, free of charge, f. o. b. cars at the railway station nearest the bridge site (to be designated by the Purchaser) any and all parts which may fail or otherwise prove to be defective within one year of the date on which the bridge is put in service.

If it should be found that the Manufacturer has varied from the Engineers' plans without receiving from them special written permission to do so, and if such variation should, within the said one year, cause any break-down or accident, the Contractor not only will be required to repair the damage to the machinery but also will be held pecuniarily responsible to the Purchaser for all expense to the latter due to such failure. If the Contractor have any objection to any features of the machinery, as designed, he must state his objection immediately in writing to the Engineers before any parts are manufactured; otherwise his objections will be ignored, if offered as excuse for defective or broken machinery.

All parts of the machinery in contact with other parts or with its supports shall be machined so as to provide true bearing; and all surfaces in rotating or sliding contact with other surfaces shall be finished true to dimensions and polished. All bearings shall be provided with oiling devices satisfactory to the Engineers. All bronze bushings shall be oil-grooved and scraped to a true fit on the journals. Other surfaces shall be left in a neat and workmanlike condition, but need not be machined for the sake of appearance. All bearings shall be attached to their supports with turned bolts of the same diameters as the holes, and dowels shall be added if the Engineers require them.

All castings shall be properly cleaned; and all fins, seams, and other

irregularities shall be removed, so that the castings shall have clean, smooth surfaces. Drainage holes of adequate size shall be drilled in all places where water is likely to collect. Unfinished bolts may have a play of one-sixteenth ($\frac{1}{16}$) of an inch in bolt holes. All turned bolts must have the diameter of the shank at least one-eighth ($\frac{1}{8}$) inch greater than the diameter of the threaded portion, and they must have a driving fit in the bolt holes.

For the swing span all track segments are to be planed on both sides and at the joints. The surfaces on which the rollers bear shall be planed to true bevel. Toothed segments forming the rack shall be accurately fitted; and particular care shall be taken to make the ends abut properly and to have the pitch of the teeth accurate at the joints. The periphery and the upper face of the teeth shall be planed, and the pitch line shall be scribed thereon. The rack segments shall be so made or so fitted to those of the track as to have the centre line of the track exactly concentric with the pitch line of the rack.

All rollers shall be turned to the correct diameters with the corners chamfered. The hubs shall be accurately bored and faced at each end.

Pivot-stands and centre castings of swing spans shall be properly finished and fitted. Special care must be taken to have the base faced truly at right angles to the axis, and turned on the circumference concentric with the axis.

The rollers, tracks, drum, and girders over drum shall be completely assembled in the shop before shipment, all holes being reamed to fit and the sections being match-marked. Every roller must have a true bearing on both the upper and the lower tracks during a complete revolution of the span. Before the assembling of the rollers is done, there must be marked on both the upper and the lower track segments a circle of the same diameter, which circles will come a trifle inside of the exterior ends of all rollers; then, after the turn-table is perfectly adjusted, each roller is to be marked where these circles touch it. After the turntable is disconnected each roller is to be set up properly in a lathe, and the exterior periphery is to be chamfered off exactly to the points marked, so that when the turntable is set up in the field, if the exterior of each roller is brought exactly to the circles on the two tracks, the rollers will all be in their proper positions. These lines on the tracks will serve also afterward to line up the rollers whenever the turntable is to be adjusted.

Steel discs and their bearings must be accurately turned and finished to gauge, and must be oil-tempered. After hardening they shall be accurately ground to their final finish. Steel and phosphor-bronze discs shall have their sliding surfaces finished to a high polish.

All journals shall be turned with a fillet at each end, unless otherwise called for on the drawings, and they shall have a good, workmanlike fit in their bearings. All hubs of wheels, pulleys, couplings, etc. shall be bored to fit close on the shaft or axle. If the hub performs the functions

of a collar, the end next to the bearing must be faced. Holes in hubs of toothed gear-wheels must be bored concentric with the pitch circle.

All gears shall be made of cast steel and shall have cut teeth. All teeth are to be of the involute type having twenty (20) degrees obliquity. All bearings shall be bushed, as shown in the drawings. All pinions shall be made of forged steel and shall have their teeth cut from the solid metal.

The principal parts of the machinery on the movable span and the portions of the structural steelwork which support it shall be assembled in the shop, and all holes for connection of the machinery to the steelwork shall be drilled while the parts are thus assembled. All bolts for connecting the various parts of the machinery to other parts or to the steelwork shall be turned to a driving fit wherever shear may come upon them.

P. 101. *Hand-Operating Machinery*

In addition to the power machinery there is to be, as shown on the accompanying drawings, machinery that will operate the movable span by man-power in case of any break-down of the other machinery or of any failure of power.

Machinery for Vertical Lift Spans

P. 102. *Tower-Sheave Bearing Connections*

Each pair of bearings shall be assembled, aligned, and adjusted to correct relative position with their shafts placed in them, on a steel plate not less than one-quarter (¼) inch thick; and holes shall be drilled through the plate corresponding to the holes for bolts in the bearings. The plate shall then be placed and aligned on the structural supports—which must be completely assembled—and the bolt holes drilled. A separate plate shall be employed for each pair of bearings; and it shall not be shorter than the total length of the shaft nor narrower than the total width of the bearings.

P. 103. *Indicator*

A mechanical indicator for the movable span shall be placed in the operator's house, and so arranged as to give the operator the exact location of the movable span at any time during the operation.

P. 104. *Counterweight and Operating Ropes and Their Attachments*

A. All wire rope shall be made by John A. Roebling's Sons Company, or some other manufacturer approved by the Engineers.

B. The counterweight ropes shall be made of plow steel wire and shall consist of six (6) strands of nineteen (19) wires each, laid around a hemp centre.

C. All ropes shall be laid up in the best possible manner and shall

be thoroughly soaked in an approved lubricant during the process of manufacture.

D. The counterweight ropes shall be made from wire which has been tested in the presence of an inspector designated by the Engineers, and which for sizes 0.076 inches to 0.190 inches in diameter exhibits the following physical properties:

a. The tensile strength per square inch shall not be less than 220,000 pounds for wire 0.190 inch to 0.151 inch diameter, nor less than 225,000 pounds for wire 0.150 inch to 0.126 inch diameter, nor less than 230,000 pounds for wire 0.125 inch to 0.101 inch diameter, nor less than 235,000 pounds for wire 0.100 inch to 0.076 inch diameter.

b. The total ultimate elongation measured on a piece 12 inches long shall not be less than 2.4 per cent.

c. The number of times a piece 6 inches long can be twisted around its longitudinal axis without rupture shall not be less than 1.4 divided by the diameter in inches.

d. The number of times the wire can be bent 90 degrees alternately to the right and to the left over a radius equal to twice its diameter without fracture shall be not less than six (6). This test shall be made in a mechanical bender so constructed that the wire actually conforms to the radius of the jaws and is subjected to as little tensile stress as possible.

E. Each rope shall, if practicable, be made in one piece. Its breaking strength, as determined by the tests described in paragraph G, shall not be less than

5,000 lbs. if ¼″ diameter	151,000 lbs. if 1⅜″ diameter
12,000 lbs. if ⅜″ diameter	176,000 lbs. if 1½″ diameter
21,000 lbs. if ½″ diameter	198,000 lbs. if 1⅝″ diameter
34,000 lbs. if ⅝″ diameter	239,000 lbs. if 1¾″ diameter
47,000 lbs. if ¾″ diameter	270,000 lbs. if 1⅞″ diameter
63,000 lbs. if ⅞″ diameter	299,000 lbs. if 2″ diameter
81,000 lbs. if 1″ diameter	378,000 lbs. if 2¼″ diameter
101,000 lbs. if 1⅛″ diameter	474,000 lbs. if 2½″ diameter
124,000 lbs. if 1¼″ diameter	

In case the breaking strength of the rope fall below the values cited above, the entire length from which the test pieces were taken shall be replaced by the Manufacturer with a new length, the strength and physical qualities of which come up to the specifications.

F. All sockets used in connection with this rope shall be forged, without welds, from solid steel, if it is possible to obtain them. In cases where this cannot be done, they may be steel castings, but only with the specific written permission of the Engineers. In every case the dimensions shall be such that no part under tension shall be loaded higher than 65,000 pounds per square inch when the rope is stressed to its ultimate strength as named above. The sockets must be attached to the rope by

a method which is absolutely reliable and which will not permit the rope to slip in its connection to the socket.

G. In order to demonstrate the strength of the rope and its fastenings, a number of test pieces, not more than 10 per cent of the total number of finished lengths which will be ultimately made, nor less than two from each original long length, and not more than twelve (12) feet long, shall be cut, and shall have sockets, selected at random from those which are to be used in filling the order, attached to their ends. These test pieces are to be stressed to destruction in a suitable testing machine. Under this stress the rope must develop the ultimate strength given in paragraph E. The sockets must be so fastened to the rope that there shall be no slipping of the rope in the basket. If slipping should occur, then the method must be changed until one is found whereby slipping can be entirely avoided. The sockets themselves shall be stronger than the rope with which they are used. If one should break during the test, then two others shall be selected and attached to another piece of rope and the test repeated, and this process shall be continued until the inspector is satisfied of their reliability, in which case the lot shall be accepted. If, however, 10 per cent or more of all the sockets tested break at a load less than the minimum ultimate strength of the rope given in paragraph E, then the entire lot shall be rejected and new ones, made of heavier type or of stronger material, shall be furnished.

The length of each rope from inside of bearing to inside of bearing of sockets shall be determined, and a metal tag having the said length stamped thereon shall be securely attached to the said rope.

The Purchaser reserves the right to test each wire rope connection, after its attachment is made, up to one-half of the ultimate strength of the rope, and if it show the least sign of weakness, it shall be rejected and replaced.

The Manufacturer shall provide proper facilities for testing, and shall make at his own expense all the tests required. All tests shall be made in the presence of an Inspector who represents and is paid by the Engineers.

All ropes shall be shipped on reels the minimum diameter of which is at least thirty times that of the ropes, and they shall be uncoiled for use by revolving the reel.

P. 105. *Rope Dressing*

As soon as the movable span is ready for operation, the **Erecting** Contractor shall furnish and apply to all ropes two coats of Whitmore's No. 1 cable dressing, manufactured by the American Specialty Manufacturing Company, of Cleveland, Ohio, or of any other dressing which the Engineers approve. The dressing shall be applied to the satisfaction of the Engineers.

I. 106. *Locking Apparatus*

As shown on the drawings, there is to be an apparatus for locking the moving span into place before it is used for passage. This apparatus is

to be operated by .... power. It is so arranged that it has to be released before the bridge can be opened for moving, and so that it has to be applied before the bridge can be used for traffic.

P. 107. *Equalizing Levers and Pins*

The equalizing levers connecting the ropes to the counterweights shall be of either forged or rolled medium steel, and all their pins which are more than four (4) inches in diameter shall be of forged steel. Pins smaller than four (4) inches in diameter shall be made of rolled machinery steel, in accordance with these specifications. The levers shall be neatly finished substantially to the dimensions shown on the drawings.

V. 108. *Counterweights*

There should be presented here a complete description of the counterweight, or else a reference to the drawings if the counterweight is shown there in detail. The method of determining the weight of the concrete to be used shall be given as well as the method of constructing the counterweight. The exact balancing of the span shall be called for. The paint to be used shall likewise be specified.

Example

The counterweights shall be constructed, as shown on the accompanying drawings, of steel frames surrounded by concrete. Before the construction of the first counterweight is begun the Contractor shall make blocks of concrete, not less than ten cubic feet in volume, of the materials to be used in the counterweights; and these blocks, when seasoned, shall be carefully measured and weighed, to determine as nearly as practicable the probable weight of the concrete in the counterweights. Forms and falsework, both subject to the Engineers' approval, shall be constructed of ample strength to support themselves and the counterweight during construction; or else the counterweights shall be built in forms attached to the counterweight frames, which shall be connected to the suspending cables that pass over the main sheaves and attach to the lifting span. Counterweights must be of correct weight to balance the span, and the Contractor shall adjust and correct them as required. The exposed surfaces of concrete of counterweights are to be painted with two coats of special concrete paint to be specified by the Engineers.

Electrical Equipment

P. 109. *Material and Workmanship (Electrical)*

In the electrical machinery the material and workmanship are to be first class in every particular, and the said machinery is to be complete

in every detail and device necessary for the perfect operation and control of the movable span. The machinery is to be manufactured and erected to the satisfaction of the Purchaser, and the Contractor must furnish the Purchaser a satisfactory guarantee to replace, free of charge, any parts which may fail or otherwise prove defective within a period of twelve (12) months after the work is officially accepted. If the Contractor have any objections to any features of the electrical equipment as designed, he must state his objections immediately in writing to the Engineers; otherwise his objections will be ignored, if offered as excuse for defective or broken apparatus.

I. 110. *Direct-current Electric Motors*

Direct-current electric motors shall be employed to perform the various operations necessary to open and close the movable span. Direct current at......volts nominal pressure shall be used. Motors of the size, character, and make specified on the drawings, or equivalent motors acceptable to the Engineers, shall be erected, installed, and properly connected with the machinery and with the controllers. Each motor shall be capable of producing the maximum starting torques and the normal torques with corresponding speeds, as indicated on the performance curves shown on the drawings. They shall further be subjected to the standard test of the American Institute of Electrical Engineers, viz.: After one-half hour's run at the rated load and voltage under normal conditions of ventilation and cooling, the temperature of any part of the motor windings shall not exceed by more than fifty (50) degrees Centigrade that of the surrounding air, if the said temperature of the surrounding air is twenty-five (25) degrees Centigrade. The permissible rise in temperature shall be increased or decreased one-half of one per cent for each degree Centigrade that the surrounding air is less than or greater than twenty-five (25) degrees Centigrade. Duplicate motors shall operate at substantially the same speed under the same load and voltage. Each motor shall be tested by the Manufacturer before shipment, and shall demonstrate its ability to meet the above requirements for temperature, torque, and speed. They shall be weatherproof, and shall have steel frames, ironclad armatures, and feet extended from frames, all as shown on the drawings.

The Contractor shall furnish, free of charge, the following additional parts for each size of motor, viz.: one armature, one set of field coils, one set of carbon brushes, and one set of back gears, if these are supplied with the motors. All these parts shall be fitted and furnished in such a manner that they may be installed in their places without further fitting or adjustment.

I. 111. *Alternating-current Electric Motors*

Alternating-current electric motors shall be employed to perform the various operations necessary to open and close the movable span. A......

phase, ... cycle alternating current at .... volts nominal pressure shall be used. Motors of the size, character, and make specified on the drawings, or equivalent motors acceptable to the Engineers, shall be erected, installed, and properly connected with the machinery and with the controllers. Each motor shall be subjected to the standard test of the American Institute of Electrical Engineers, viz.: After one-half hour's run at the rated load, voltage, and frequency, and under normal conditions of ventilation and cooling, the temperature of any part of the motor windings shall not exceed by more than fifty (50) degrees Centigrade that of the surrounding air, if the temperature of the surrounding air is twenty-five (25) degrees Centigrade. The permissible rise in temperature shall be increased or decreased one-half of one per cent, for each degree Centigrade that the surrounding air is less than or greater than twenty-five (25) degrees Centigrade. Duplicate motors shall operate at substantially the same speed under the same load and voltage. Each motor shall be tested by the Manufacturer before shipment, and shall demonstrate its ability to meet the above requirements for temperature and the requirements for torque and speed as given on the drawings. They shall be weatherproof, and shall have steel frames and feet extended from the frames, all as shown on the drawings.

The Contractor shall furnish free of charge the following additional parts for each size of motor, viz.: **(Give the parts for the particular type of motor used that are subject to destruction by the breaking down of the insulation, etc.).**

I. 112. *Controllers and Resistances*

*There shall be one .... type controller located in the **operator's (machinery)** house, capable of governing the operating motor. The controller shall be of the .... type with .... steps, and shall be so arranged and wired that the solenoid brake on the armature shaft of the motor will be released on the first point of the controller and the motor started on the second point of the controller. The controller shall be equipped with magnetic blow out, and, if fitted with interlocking reversing cylinder, shall be so interlocked that the reverser cannot be thrown when the motor is taking current.

Suitable resistance of ample capacity shall be furnished so that the motor can be started and operated from standstill to full speed without causing injurious sparking at the commutators of the motor and without shock or jar to the bridge. All resistances shall be mounted so as to be free from injurious vibration and so as to have free ventilation.

(Add similar clauses for additional motors, if other motors are employed, as for end lifts, locks, etc:)

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* This clause as written assumes that there is one motor and one controller for operating the span. If there be more than one motor or controller, it must be suitably modified.

All motor and manual controls shall be so interlocked that no successive operation can take place until the preceding operation has been properly performed.

V. 113. *Electric Power Wiring and Electric Cables*

This clause will depend on the type of movable span employed. In the case of a draw-span it is generally necessary to carry the cables from the fixed spans under the river to the pivot pier, although in some instances it is possible to carry the wires overhead to the centre of the span. In lift and bascule spans the supply wires, as a rule, can be carried on the superstructure without passing under the river.

This clause should give the source of supply at which the Contractor has to make his connections. It should specify the size, construction, and characteristics of the wires and cables required, the size and quality of conduits, and the apparatus for protecting the feeders, as well as the layout and workmanship of the complete system.

EXAMPLE

All wiring from a source of supply not more than one hundred (100) feet distant from each end of the movable span, together with all necessary apparatus and appurtenances, shall be furnished and placed by the Contractor.

All wiring on the spans shall be double-braided, rubber-covered, copper wire of ample capacity to carry the currents required by the motors for maximum loads to the switchboard with drop in potential not to exceed five (5) per cent. No wire shall be less than No. 12 B. & S. gauge. The wires shall be drawn, without injury to either themselves or the insulation, into loricated pipe conduits or equivalent conduits acceptable to the Engineers. These conduits shall have as few bends as possible, and shall be directly connected to all apparatus so as to provide a weatherproof housing for the wires. Each feeder shall be protected by a pole switch, fuse, and lightning arrester mounted on a non-combustible and non-absorbent insulating base. (For alternating currents all the phase wires shall be placed in one conduit.)

FOR THE VERTICAL LIFT SPAN.—Running vertically on the towers there shall be No. 000 trolley wires properly fastened to and insulated from them as shown on the drawings. These trolley wires shall be connected to the sources of supply by 300,000 cm. double-braided, rubber-covered cables composed of nineteen (19) strands of tinned copper wire of not less than ninety-eight (98) per cent conductivity. Collectors attached to the feed wires on the span shall engage the trolleys for the full movement of the span.

FOR THE DRAW SPAN.—The conductors for the swing span shall consist of steel-armored, subaqueous cables with two independent conductors,

one for the supply and one for the return current. Each cable shall be of sufficient capacity to carry safely the necessary current to operate the bridge with full overload on the motors as specified. Each cable shall be composed of nineteen strands of tinned copper wire of not less than ninety-eight per cent conductivity. The insulating wall of rubber shall not be less than five thirty-seconds of an inch thick, containing not less than thirty per cent of pure Pará rubber. There shall be one winding of tape, and a lead sheath three thirty-seconds of an inch thick, containing three per cent of tin alloy; also a substantial jute and asphalt covering and an armor of galvanized steel wire of suitable size for the diameter of the cable. The cables shall show at sixty degrees Fahrenheit an insulating resistance of five hundred megohms per mile after five minutes of electrification. These cables shall be brought up through the centre pivot, with collector rings to carry the current to the controlling apparatus while the bridge is swinging. These collector rings shall be protected by movable metallic casings.

The subaqueous cables shall be carried across the channel from the fixed span to the pivot pier in a trench to be excavated in the river-bed not less than five feet deep and filled up after the cable is placed.

Proper return circuits shall be provided to carry current from the swing span to the ground circuit.

P. 114. *Switches and Switchboards*

The switchboard shall be of first-quality slate, so large that all meters, switches, cut-outs, fuses, etc., thereon may be safely and easily reached and operated by the bridge operator. All switches, cut-outs, and buttons shall have suitable name plates and shall be properly labeled in accordance with their purpose and use. The switchboard shall be mounted on a substantial iron support braced to the wall.

An automatic circuit breaker equal in quality to the laminated type I-T-E Standard and of ample capacity shall be placed on the motor circuit between the feeders and the switchboard devices. Each cable, each line of motors, and each line of lighting, signal, indicator, or other circuit shall be protected by suitable fuses of a pattern approved by the Engineers. Switches of the quick-break, railway type shall be provided for each feeder, and for each motor circuit, each solenoid circuit, each signal circuit, and each lighting circuit, also for bridge lights and semaphore lights. An indicating wattmeter and a voltmeter, made by the Western Electrical Instrument Company, or equivalent meters acceptable to the Engineers and of the capacity called for on the drawings, shall be furnished and mounted on the switchboard. All switchboard appurtenances necessary for the satisfactory operation of the electrical apparatus described in these specifications shall be furnished, whether specifically mentioned or not, and bidders will submit with their tenders a complete statement

of the appurtenances included. One set of extra carbons for each kind of circuit breaker and ten extra fuses of each kind used shall be furnished.

All switches, circuit breakers, and other appurtenances shall have ample capacity for the greatest current the motors may use.

P. 115. *Grounds*

All ground connections to the structure shall be made with proper soldered terminals secured to a copper plate of ample area fastened to the return street railway circuits. Care shall be taken to locate the connections so that there shall be ample metal and proper circuits to return the current without damage to the structure. Ground trolleys, similar to the feeder trolley, shall be placed at both ends of the fixed structure. They shall have ample ground-connection separate from the structure.

P. 116. *Solenoid Brake*

Each motor shall be supplied with a standard solenoid brake of the same manufacture as the motor, mounted on the armature shaft and supported on the steel work. The brake shall be released on the first point of the controller and applied when the current is turned off, the motor being started on the second point of the controller. The brake shall be of ample capacity to brake the motor efficiently. One (1) extra spool, two (2) extra shoes, and six (6) extra springs for the solenoid brake shall be furnished.

P. 117. *Limit Switches*

Suitable limit switches shall be supplied and shall be so arranged that the electric current will be automatically cut off and so that the solenoid brake will be applied to the motor governed by it, when the movable span approaches either limit of its motion. The limit switch shall be so constructed that the point of cut-off shall be positive but adjustable by the operator. A suitable short-circuiting spring switch shall be furnished and placed convenient to the operator, so that power may be supplied to the motor after the limit switches have operated.

V. 118. *Service Lights and Roadway Lights*

Wherever a movable span is employed, it is necessary to provide service lights in the machinery house, operator's house, gate tenders' houses, and stairs, and at other points on the span where machinery or walkways to the machinery are to be found. The current for the service lighting system is generally taken from the feeders for the operating machinery. Where highway traffic crosses a structure, roadway lights are generally used. This is invariably the case on city bridges. Either one or both of these lighting systems may be required, depending on the nature of the structure; and this clause must be written with that in

view. The circuit for the roadway lighting system should be independent of the circuit for service lights where both systems are used; for, as a rule, the source of supply of current is different, because alternating current is preferable for the roadway lights and direct current for the operation of the span and the service lights, where both currents are available.

This clause should give the system employed, whether series or parallel (and in the latter case the number of wires used). The voltage or current, the number and type of lamps, the number and style of globes, the kind of wire and conduits for wire, switches, protection for the circuit, and all details necessary for the complete and proper installation of the system should be specified. Usually, merely the number of lamps is specified for the service system, and these are expected to be placed in series so that each lamp will have the proper voltage.

Example (Service Lights)

There shall be placed in each machinery or operator's house ten (10) sixteen (16) c.-p. lights disposed about the room as may be directed; and there shall be placed ten (10) sixteen (16) c.-p. lights distributed among the outside machinery and at stair landings, as may be directed, the lights on the stairs to be controlled by a switch at foot of stairs as well as on the switchboard.

In each gate-tender's house there shall be placed two (2) sixteen (16) c.-p. lights; and on each of the four roadway gates there shall be placed five (5) sixteen (16) c.-p. lights with red globes. Lights located outside shall have weatherproof sockets. Each set of lights shall be controlled by proper switches on adequate switchboards.

All lamps, globes, sockets, wires, cut-outs, conduits, and other appurtenances necessary for the complete operation of the service lights shall be provided. The wiring shall be run in loricated pipe conduits, or other conduits approved by the Engineers; and these conduits shall be securely fastened to the structure. All wires shall be double-braided, rubber-covered, copper wire, none of which shall be smaller than No. 12 B. & S. gauge. They shall be drawn into the conduits without injury to either the wire or its insulation, and all joints in the wire shall be cleaned, soldered, and double-taped with rubber tape and friction tape.

Example (Roadway Lights)

The bridge shall be illuminated by tungsten lamps surrounded by clear glass globes, fourteen (14) inches in diameter. Each globe shall contain two one-hundred (100) watt tungsten lamps with water-proof sockets, suspended from a bracket attached to the trusses. A pliable rubber bushing shall be used in attaching the lamp sockets to the bracket,

so as to relieve the lamps of any jar or vibration caused by moving loads on the bridge.

The lighting system shall be three (3) wire, two hundred and twenty (220) volt, with one hundred and ten (110) volts between the neutral wire and either outside wire. A connection to the source of supply shall be provided at each end of the bridge. A control box shall be placed at each source of supply and shall contain the necessary switches and fuses to protect and control the lights. Between the control box and the feeder service there shall be placed a lightning arrester, a pole switch, and a fuse, mounted on a non-absorbent, non-combustible, insulating-base and enclosed in a weather-proof box.

Thirty-six (36) lights, four (4) on each span, each containing two (2) lamps, are required.

The wiring shall be run in loricated pipe conduits, or other conduits approved by the Engineers; and these conduits shall be securely fastened to the structure. All wires shall be double-braided, rubber-covered copper wire, none of which shall be smaller than No. 12 B. & S. gauge. They shall be drawn into the conduits without injury to either the wire or its insulation, and all joints in the wire shall be cleaned. soldered and double-taped with rubber tape and friction tape.

All lamps, globes, sockets, wires, cut-outs, conduits, and other appurtenances necessary for the complete operation of the lighting system shall be provided. All work shall conform to the National Electric Code for this particular class of work, and all materials and workmanship shall be first class in every respect, and subject to the inspection and approval of the Engineers.

Example (Roadway Lights)

The structure is to be illuminated by an electric lighting system. There shall be furnished and installed all lamps, globes, conduits, wiring, and all other apparatus and appurtenances necessary for a complete series Tungsten Lighting System, taking current from the Kansas City Electric Light Company's 6.6 ampere constant current feeders at the east end of the structure. There will be two circuits. The circuit for lighting the upper roadway will have sixty 125 watt, 6.6 ampere, constant-current-series, tungsten lamps. Each lamp will be supported on a cast-iron standard and will be surrounded by an opal glass globe 14 inches in diameter. The circuit for lighting the lower roadway and the stairways will have fifty-six 75 watt, 6.6 ampere, constant-current, series, tungsten lamps. Each lamp shall be supported on a cast-iron standard or bracket and shall be surrounded by an opal globe twelve (12) inches in diameter. All wiring shall be drawn into Sherardized steel pipe conduits of a satisfactory type so as to be free from all flaws or mechanical injuries. All wires shall be No. 6 high-tension, lead-covered, okonite, stranded copper wire of best quality. The conduit shall be encased in the concrete as the

latter is placed; and it shall be properly supported and arranged so that later the wire may be drawn into place. Suitable expansion joints shall be provided, and all connections shall be made in the conduits so that they shall conform properly to the requirements of the structure. Cut-outs shall be provided for each light. All joints between pipes and between pipes and boxes shall be made water tight. The entire lighting system shall be constructed in a thoroughly workmanlike manner and to the satisfaction of the Engineers.

V. 119. *Signal and Semaphore Lights*

The United States Government requires the installation of a system of lights to mark the clear channel for all navigable streams and to show the position of the movable span where such a span is used. This clause should specify the requirements for the particular type of span employed.

Example

Signal lights, as required by the United States Government, shall be provided and placed on the piers and the movable spans.

For the lift span, the following lights shall be furnished. At each end of each tower pier there shall be one red light placed near the top of the pier. Vessel signal lamps shall be attached to the lower chords on both the up- and the down-stream sides of the lift span, each signal consisting of a double electric lantern having eight-inch Fresnel lenses colored green and red. They shall be wired so as to be controlled from the operator's stand to show either green or red; and there shall be provided in the operator's house a green and a red lamp so mounted as to denote which circuit is glowing.

For the swing span the following lights shall be furnished: at each end of the draw protection, at each end of each side pier, and at each side of the pivot pier, there shall be one red light placed near the top of the pier. Three signal lamps shall be placed on the top of the truss span, one at each end over the portal and one on the top of the central tower, each signal consisting of a double electric lantern having eight-inch Fresnel lenses colored green and red. They shall be wired so as to be controlled from the operator's stand to show either green or red, and a green and a red lamp so mounted as to denote which circuit is glowing shall be provided in the operator's house.

All lights, both red and green, shall be visible on a dark night with a clear atmosphere at a distance of not less than 2,000 yards. All lights are to be shown from half-round, pressed, Fresnel lenses eight (8) inches in diameter with an arc of illumination of one hundred and eighty (180) degrees. The lamps are to be enclosed in substantial metal lanterns, firmly attached as may be approved. The lights on piers at the sides of the channel shall be controlled from the gate-tender's house.

All lanterns, lamps, sockets, wires, conduits, and other appurtenances necessary for the complete operation of the signal service and semaphore lights shall be provided. The wiring shall be run in loricated pipe conduits or other conduits approved by the Engineers; and they shall be securely fastened to the structure. All wires shall be double-braided, rubber-covered, copper wire, none of which shall be smaller than No. 12 B. & S. gauge. They shall be drawn into the conduits without injury to either the wire or its insulation, and all joints in the wire shall be cleaned, soldered, and double-taped with rubber tape and friction tape.

P. 120. *Indicator Lights for Span Operation*

Signal lamps shall be provided to indicate the open and closed positions of the **locks, end-lifts, gates and span.** They shall be located in the operator's house on the switchboard. They shall show clear when the span is ready for bridge traffic, and shall show red for open positions when the span is closed to traffic. Each indication must be sufficiently accurate to permit safely the carrying out of the succeeding operations.

Adequate contacts, properly insulated, shall be attached to the metalwork as indicated on the drawings, or as may be approved by the Engineers. All wiring for the signal system shall generally conform to the requirements of wiring for the lighting system and shall be carried in approved conduits. The signal lights shall be mounted on a slate panel, and each light shall be properly labeled.

V. 121. *Vessel Signals*

In some localities special signals are required for vessels. Where such is the case, this clause should outline the equipment and installation completely.

Example

The movable span shall be provided with a vessel signal to indicate to navigators that their signals have been heard and whether the bridge will be opened. Each signal shall consist of a pole supporting a copper ball twenty-four (24) inches in diameter made of No. 22 gauge copper and painted red. The ball shall be raised or lowered by a tiller rope extending to the operator's stand, and the signal shall be so situated that when the ball is raised it shall be visible to navigators approaching the bridge from either up- or down-stream.

P. 122. *Electric Siren*

For the purpose of signaling approaching vessels, there shall be provided and installed two electric sirens, together with battery, wiring, conduits, push button switch, and all other appurtenances necessary for proper operation. The sirens shall be of such size as to be easily heard

by those on board of approaching vessels; and they shall be placed outside of the house with the bell of one siren pointing up-stream and the bell of the other siren pointing down-stream. The switch for operating the sirens shall be attached to the controller stand in the operator's house. The entire equipment and layout shall meet the approval of the Engineers.

P. 123. *Signal Bells*

The Contractor shall furnish and install complete with batteries, wiring in conduits, switches, and all connections, one electric, vibrating signal-bell. The said bell is to be located at about the middle of the movable span, as called for by the plans. It is to be made with a substantial cast-iron base and with all working parts adequately protected in a weather-proof case. The gong is to be fifteen (15) inches in diameter and made of bell metal. The electrical contacts shall be of platinum. There shall be provided in the operator's house an automatic push button or switch for the bell, so arranged that by pressing the button once, it will continue to ring for twenty (20) seconds and then stop until the button is pressed again. The conduits containing the wires shall be properly fastened to the steel work, being placed so as to be inconspicuous.

I. 124. *Machinery House Crane*

The Contractor shall furnish and put in place in the machinery house, as per the detailed plans, a .... (......) ton, hand-operated crane with suspended, four-wheel trolley, equipped with a .... (......) ton Yale and Towne Triplex Hoist, or other hoist acceptable to the Engineers.

P. 125. *Interlocking Apparatus*

There is to be an approved system of interlocking for the handling of bridge traffic, for which drawings are to be prepared by the Contractor **for the Manufacture of the Metalwork** and submitted to the Engineers for their approval before work upon it is started.

P. 126. *Gasoline Engines*

Gasoline engines of the size and make specified on the drawings, or equivalent engines acceptable to the Engineers, shall be erected, installed, and properly connected with the machinery. Each engine shall be capable of developing an amount of brake horse-power ten (10) per cent in excess of the rated capacity when operating at the normal rate of speed with gasoline as fuel. It shall be tested at the manufacturer's plant to meet this condition before shipment.

Each engine shall be furnished with a magneto, igniters, battery, switchboard, oiling devices, carburetors, tanks for oil, water, and gasoline, air-pump, air-compressor, piping, wiring, wrenches, and all other accessories necessary for starting and for successful operation.

P. 127. *Installation of Machinery*

All machinery and machinery parts shall be prepared, erected, adjusted, painted, oiled, and put in perfect operating condition. If the Contractor **for Erection** have any objection to any features of the machinery, as designed, he must state his objections in writing to the Engineers within ten days after signing his contract; otherwise his objections will be ignored, if offered later as excuse for defective erection, adjustment, or operation. The Contractor **for Erection** shall furnish grease for guides, oil for machinery, and all such supplies to complete the mechanical parts for operation. The Contractor **for Erection** shall also maintain all machinery in adjustment and shall perform all labor and operate the bridge for the Purchaser's service for a period of sixty (60) days after it has been accepted by the Purchaser and put into service, without additional payment. The Purchaser will furnish the necessary gasoline and oil for such operation.

P. 128. *Paint*

The paint for the metalwork shall be Detroit-Superior Graphite, Nobrac, the Goheen Carbonizing Coating, red lead, or any other paint which the Engineers shall name, it being understood that the paint to be used shall be that chosen by the Engineers after the contract is let, and that if the said paint cost the Contractor more than **one dollar and fifty cents** (**$1.50**) per American gallon delivered at the works of the Manufacturers of the metalwork, or at the bridge site, the Contractor shall be paid extra the actual excess cost of the paint over **one dollar and fifty cents** (**$1.50**) per American gallon.

P. 129. *Painting*

All metalwork, before leaving the shop, shall be thoroughly cleansed from all loose scale, rust, and dirt, and shall be given one coat of red lead ground in linseed oil, or any other priming coat required by the Engineers, which coat shall be thoroughly dried before the metalwork is loaded for shipment. It is absolutely essential that the entire surface of the metalwork be thoroughly cleansed by the most effective known methods, such as the use of wire brushes and scrapers. All surfaces coming in contact shall be particularly well painted before being riveted together. Bottoms of bed-plates, bearing-plates, and any other parts which are not accessible for painting after erection shall have three (3) coats of paint, one at the shop, the other two in the field, before erection. Pins, bored pinholes, turned friction-rollers, and all other polished surfaces shall be coated with white lead and tallow before shipment from the shop. Graphite or oil should be used as the lubricant for reaming; but should soap-suds be employed, all parts of the metal affected thereby must be washed thoroughly and dried before any painting is done thereon.

After the structure is erected, the metal work shall be thoroughly cleansed from mud, grease, or any other objectionable material that may be found upon it, the rivet-heads and areas on which the paint has been damaged shall be painted, then the entire surface shall be thoroughly and evenly covered with two (2) coats of the paint adopted. All three coats of paint given to the metal work are to be of distinctly different shades or colors; and the second coat must be allowed to dry thoroughly before the third coat is applied. No thinning of paint with turpentine, benzine, or other thinner will be allowed without special written permission from the Engineers. No painting is to be done in wet or freezing weather, unless it be under cover where the temperature is above the freezing point.

All painting is to be done in a thorough and workmanlike manner, to the satisfaction of the Engineers, and no paint whatever is to be used on the structure without first being approved by the Engineers. All the materials for painting shall be subject at all times to the closest inspection and chemical analysis; and the detection of any inferior quality of such material, in either shop or field, shall involve the rejection of all such suspected material at hand and the scraping and repainting of those portions of the work which, in the opinion of the Engineers, were defectively painted on account of such inferior material.

All recesses which would retain water or through which water could enter must be filled with thick paint or some waterproof cement before receiving final painting. All surfaces so close together as to prevent the insertion of paint brushes must be painted thoroughly by using a piece of cloth instead of the brush.

P. 130. *Timber*

All timber remaining permanently in the structure must be of best quality, sawed true and out of wind, and free from wind-shakes, large or loose knots, decayed wood, worm holes, or any other defect that, in the opinion of the Engineers, would impair its strength or durability; and, unless it be used under water, not more than ten (10) per cent of the area of any stick at any cross-section shall be sap wood. Timber remaining permanently under water shall be first-class, square-edged, and sound. All timber and lumber shall be surfaced on all four sides, and shall conform to the net dimensions specified on the drawings. In paying for timber by the thousand feet B. M., only the actual net amount furnished in place will be allowed for, notwithstanding trade usage being to the contrary, and bidders should figure accordingly.

All timber left in the structure above low water shall be long-leaf yellow pine, Douglas fir, cedar, or other first-class timber, of a quality satisfactory to the Engineers. Timber left permanently below low water may be of any variety which, in the opinion of the Engineers, is suitable and of adequate strength.

I. 131. *Preservation of Timber*

All treated timber is to receive .... (......) pounds of creosote oil per cubic foot. The process of treatment shall be such that the wood is first softened and the saps and resins dissolved by steam, then removed from the wood by the application of a vacuum, after which the creosote oil shall be injected by pressure until the amount required above has entered the pores of the wood. The oil used shall be the best obtainable grade of coal-tar creosote; that is, it must be a pure product of coal-tar distillation, and must be free from admixture of oils, other tars, or substances foreign to pure coal-tar; it must be completely liquid at thirty-eight (38) degrees Centigrade, and must be free from suspended matter; and the specific gravity of the oil at thirty-eight (38) degrees Centigrade must be at least 1.03. When distilled according to the common method, that is, using an eight (8) ounce retort, asbestos covered, with standard thermometers, bulb one-half (½) inch above the surface of the oil, the creosote, calculated on the basis of the dry oil, shall give no distillate below two hundred (200) degrees Centigrade, not more than five (5) per cent below two hundred and ten (210) degrees Centigrade, and not more than twenty-five (25) per cent below two hundred and thirty-five (235) degrees Centigrade. The residue above three hundred and fifty-five (355) degrees Centigrade (if it exceeds five (5) per cent in quantity) must be soft. The oil shall not contain more than three (3) per cent of water.

If practicable, all timber to be creosoted shall be cut to exact dimensions before being treated, so that it will fit into position without trimming at the site. Any creosoted timber that has to be cut after treatment must have the cut surfaces thoroughly covered with hot asphaltum before being placed in position.

V. 132. *Track-Rails and Their Connections*

This clause shall state whether rails are to be provided for steam or electric railway, or both, and shall give the standard used and the section number, weight, length, and process of manufacture. It also shall give complete details as to splices, bolts, spikes, bonds, tie-bars, and all other appurtenances necessary for the complete installation of the track.

Example

The railway track rails shall be of the A. S. C. E. section weighing eighty (80) pounds per yard; and the street railway track rails shall be of the Lorain Steel Company's Section 79, No. 373, weighing seventy-nine (79) pounds per yard, or other rails of equivalent section and weight which are satisfactory to the Engineers. Railway rails shall be made by the open-hearth process.

The street railway rails shall be connected by twenty-two (22) inch angle splice bars having eight (8) bolts one (1) inch diameter in each joint, the holes in the rails and bars to be drilled according to the Lorain Steel Company's Standard for this rail and joint. Standard rail bolts one (1) inch in diameter with elliptical shank and hexagonal nuts are to be furnished. The joints in each pair of rails are to be placed opposite. All rails, splice bars, tie bars, bolts, connections, and appurtenances of every kind shall be made by the open-hearth process and in accordance with the Lorain Steel Company's specifications for standard, open-hearth, grooved-girder or high tee rails, but the rails shall be sixty (60) feet long, except when variation from this length is necessary.

V. 133. *Paving*

In this clause the kind of pavement and its supporting base should be fully described in every detail. Ordinarily in the East it is best to use paving blocks of creosoted, long-leaf, Southern yellow pine; and in the West, creosoted Douglas fir; but sometimes asphalt or bitulithic pavement will be called for.

The following are types of the specifications for paving.

V. 134. *Creosoted Block Pavement*

This clause should specify the kinds of timber which can be employed, the dimensions of the blocks, the amount of creosote to be injected, the composition of the creosote and the testing thereof, the method of treatment, the base, and the cushion or bedding layer on which the blocks rest; and it should also give a detailed description of the method of laying the blocks. Only one kind of timber should be permitted on any one structure. About eighteen (18) pounds of creosote oil per cubic foot should be used for yellow pine, and twelve (12) pounds for Douglas fir.

Example

The pavement is to be of creosoted, long-leaf, Southern yellow pine, Norway pine, Douglas fir, or tamarack blocks; but only one kind of wood is to be used on the structure.

The blocks must be cut from a good grade of timber, which must be well manufactured, full-size, square-butted, square-edged, and free from the following defects: checks, unsound, loose, or hollow knots, knot-holes, worm-holes, through shakes, and round shakes that show on the surface. The number of annular rings in the one-inch space which begins one inch from the centre of the heart of the block shall be not less than six. In the case the block does not contain the heart, the one inch to be used shall begin with the annular ring which is nearest to the centre of the heart. No block shall contain less than fifty (50) per cent of heart wood.

The blocks shall be from six (6) to ten (10) inches long, averaging not less than eight (8) inches. The depths of the blocks shall be four (4) inches, and their widths three and a half (3½) inches. A variation not exceeding one-sixteenth ($^1/_{16}$) of an inch shall be allowed in either the depth or the thickness from the dimensions specified.

The preservative to be used shall be a product of coal gas or coke-oven tar, which shall be free from all adulterations and shall contain no raw or unfiltered tars, petroleum-compounds, or tar-products obtained from processes other than those stated. The specific gravity shall not be less than one and eight-hundredths (1.08) nor more than one and fourteen hundredths (1.14) at a temperature of thirty-eight (38) degrees Centigrade. Not more than three and one-half (3.5) per cent shall be insoluble by continuous hot extraction with benzol and chloroform.

On distillation, which shall be made exactly as described in Bulletin No. 65 of the American Railway Engineering Association, the distillate based on water-free oil shall be within the following limits, and an average of a number of tests shall show a mean of these percentages, viz.:

Up to 150 degrees Centigrade	Nothing must come off
" 170 " "	0 to 0.5 per cent
" 210 " "	2 to 6 per cent
" 235 " "	8 to 16 per cent
" 315 " "	30 to 45 per cent
" 355 " "	45 to 60 per cent

The specific gravity of the distillate distilling between 235 degrees and 315 degrees Centigrade shall not be less than one and two-hundredths (1.02) at sixty (60) degrees Centigrade compared with water at the same temperature.

The preservative shall not contain more than three (3) per cent of water.

The manufacturer of the blocks shall permit full and complete sampling at all times and places, and shall, if required, furnish satisfactory proof of the origin of the preservative.

The blocks shall be treated in an air-tight cylinder with the preservative hereinbefore specified. They shall be subjected to steam at a temperature between 220 and 240 degrees Fahrenheit, after which a vacuum of not less than twenty (20) inches shall be drawn, the temperature at the same time being maintained at from 150 to 240 degrees Fahrenheit. While the vacuum is still on, the preservative oil, heated to a temperature between 170 and 200 degrees Fahrenheit, shall be admitted, and the pressure shall be gradually applied until a sufficient amount of the preservative oil has been forced into the blocks. Not more than ten (10) per cent of excess above the amount specified shall be allowed. The blocks, after treatment, shall show satisfactory penetration of the preservative through and through; and all blocks that have been warped, checked, or otherwise injured in the process of treatment shall be rejected.

The surface of the blocks shall be clean and free from any deposit of tar or other foreign substance.

The blocks shall be inspected at the plant, and the Manufacturer of the blocks shall equip his outfit with all the necessary gauges, appliances, and facilities to enable the Inspector to satisfy himself that all the requirements of the specifications are fulfilled. He shall allow an authorized representative of the Engineers to inspect all materials and all parts of the plant during the manufacture of the paving blocks.

After delivery at site the blocks shall be subject to a further inspection, and all imperfect blocks shall be rejected and removed by the Contractor.

The base of the pavement shall be of concrete, as shown on the drawings, finished off smooth on top to correct elevation, after which it is to be covered to a depth of about one-eighth (1/8) of an inch in small areas with hot asphaltum as the blocks are laid.

Upon the bed thus prepared the blocks shall be carefully set with the fibre of the wood vertical in straight, parallel courses, except that at least one row of blocks shall be placed parallel with the curb and three-quarters (3/4) of an inch therefrom.

The blocks shall be laid by setting them loosely together on the cushion coat, but no joint shall be more than one-eighth of an inch in width, excepting that on grades of three (3) per cent or over, a line of three-eighths (3/8) by one and one-quarter (1 1/4) inch creosoted lathing transverse to the structure shall be placed between the lines of blocks and in contact with the said cushion. None but whole blocks shall be used, except in starting or completing a course or in such other cases as the Engineers may direct, and in no case shall the lap joint be less than two (2) inches. Closures shall be carefully cut and trimmed by experienced men. The portions of the blocks used for closure must be free from check or other fracture, and the cut end must have a surface perpendicular to the top of the block and cut to the proper angle to give a close, tight joint. All cut surfaces are to be thoroughly covered with hot asphaltum before laying.

Along the curb there shall be one or more longitudinal joints filled with hot asphaltum, the total width of the said joint or joints at each curb being one-half (1/2) inch for each ten feet of total clear roadway. This is to be done in order to provide against a possible lateral expansion of the pavement due to the blocks drying and afterward absorbing moisture.

After the blocks are placed, they shall be rolled parallel and diagonally to the curb by a steam roller weighing at least five tons until the surface becomes smooth and is brought truly to the correct grade and contour. After the blocks have been thoroughly rolled, the joints between them shall be filled half way up with hot asphaltum, and the remaining spaces shall be filled with hot pea-gravel or hot stone chips in case that lath be employed, or otherwise with hot, fine, screened sand; then the surface shall again be rolled.

After inspection by the engineers, the surface of the wood-block pavement shall be covered to a depth of about one-half (½) inch with fine screened sand. This sand is to be left upon the pavement for such time as may be directed by the Engineers, after which it shall be swept up and taken away by the Contractor.

The Contractor will be required to give a guarantee, satisfactory to the Purchaser, that the preservative used will keep the blocks free from decay for a period of ten (10) years, and to furnish, free of charge at the bridge site, an adequate number of paving blocks to replace all those which shall decay wholly or in part within ten (10) years from the date of the completion of the bridge.

V. 135. *Asphalt Pavement*

This clause should give complete specifications for all the materials entering into the pavement and for its construction. The total thickness of the binder and the wearing surface will depend on the traffic crossing the structure as well as on the length of the span when it is necessary for economy to keep down the dead load. This thickness will vary from two (2) inches for long spans and light traffic to three and one-half (3½) inches for short spans and heavy traffic. The greater thickness is preferable whenever funds are available for its adoption.

Example

Description.—The pavement shall consist of, first, a concrete base as shown on the drawings; second, a binder course one and a half (1.5) inches in thickness when compressed; and, third, an asphalt wearing surface two (2) inches in thickness when compressed.

Foundation.—The concrete for the foundation shall be mixed as hereinafter specified, the upper surface being parallel to and three and a half (3.5) inches below the finished surface of the paving. After being laid, the surface of the concrete shall be protected from rain, if necessary, and shall be sprinkled with hose and rosehead sprinkler as frequently as may be required by the Inspector until it is sufficiently set.

Materials.—The materials used for the binder and wearing courses must comply with the requirements of these specifications, and must be mixed in definite proportions by weight. All materials and the proportions thereof used must be satisfactory to the Engineers.

Methods of Testing.—All tests must be conducted as hereinafter specified. All penetrations at 77 degrees Fahrenheit are expressed in hundredths of a centimeter and are to be taken (except where otherwise specified) with a No. 2 needle acting for five (5) seconds without appreciable friction under a total weight of one hundred (100) grams.

Refined Asphalts.—The refined asphalts admitted under these specifications shall be prepared from a natural mineral bitumen, either solid or

liquid, or from combinations thereof, by such methods of refining as will secure a product complying with the requirements hereinafter given.

The preparation and refining of all asphalts admitted under these specifications shall be subject to such inspection at the paving plants and refineries as the Engineers may direct. Every refined asphalt admitted under these specifications, if required by the Engineers, shall be equal in quality to the recognized standard for its particular kind or type of asphalt. If desired, the Contractor may use an asphalt cement prepared at the refinery. To be acceptable this asphalt cement must comply with the foregoing general requirements for refined asphalt, as well as requirements *a*, *b*, *c*, *d* and *e* for asphalt cement.

Asphalt obtained by the refining of natural liquid bitumens shall not be reduced in the refining process to a penetration, at 77 degrees F., of less than 30.

All refined asphalts admitted under these specifications must comply with the following requirements:

a. All shipments of refined asphalt of any one kind shall have the batch number plainly marked on each package or container, shall be uniform in consistency and composition, and shall not vary from maximum to minimum more than fifteen (15) points in penetration at 77 degrees F.

b. Ninety-eight and one-half (98½) per cent of the total bitumen of all refined asphalts shall be soluble in carbon tetrachloride.

c. When made into an asphalt cement by the use of such materials and methods as are described in these specifications, they must produce an asphalt cement complying with all the requirements elsewhere set forth herein for asphalt cements.

Fluxes.—These shall be the residues obtained by the distillation of paraffine, asphaltic petroleums, or semi-asphaltic petroleums. They shall be of such character that they will combine with the asphalt to be used to form an acceptable and approved asphalt cement complying with the requirements of these specifications. All residua must pass the following general tests:

a. They must have a penetration greater than three hundred and fifty (350) with a No. 2 needle at 77 degrees F. under fifty (50) grams weight for one second.

b. They shall have a specific gravity at 77 degrees F. between 0.92 and 1.02.

c. When twenty (20) grams of the flux are heated for five (5) hours at 325 degrees F. in a tin box two and one-quarter (2¼) inches in diameter and three-quarters (¾) of an inch deep after the manner hereinafter prescribed, the loss shall not exceed five (5) per cent by weight, and the residue left after such heating shall flow at 77 degrees F.

d. They shall not flash below 350 degrees F. when tested in a closed oil tester.

e. They shall be soluble in carbon tetrachloride to the extent of not less than ninety-nine (99) per cent.

Binder Stone.—This shall be clean, hard, broken stone, free from any particles that have been weathered or are soft. If the stone does not contain the proper amount of material passing the one-half (½) inch screen, the deficiency may be made up by the addition of gravel or sand. Ninety-five (95) per cent of the binder aggregate shall pass a screen having circular openings the diameter of which shall be three-quarters (¾) of the thickness of the binder course to be laid. The remaining five (5) per cent shall not exceed in their smallest dimension the thickness of the binder course to be laid. The binder aggregate shall be so graded from coarse to fine as to have the following mesh composition (sieves to be used in the order named):

Passing 10 mesh	15 to 35%
Passing ½ inch circular opening and retained on 10 mesh	20 to 50%
Total passing ½ inch	35 to 85%

(N. B.). The above limits as to mesh composition are intended to provide for such permissible variations as may be rendered necessary by the available sources of supply and the character of the work to be done. The mesh composition and character of the stone may be varied, within the limits above specified, at the discretion of the Engineers, depending upon the kind of asphalt used and the traffic conditions.

Sand.—The sand shall be hard, clean grained, and moderately sharp. On sifting it shall have the following mesh composition (sieves to be used in the order named):

Passing 200 mesh	0 to 5%
Passing 100 mesh and retained cn 200 mesh	10 to 25%
Passing 80 mesh and retained on 100 mesh	6 to 20%
Passing 50 mesh and retained on 80 mesh	5 to 40%
Passing 40 mesh and retained on 50 mesh	5 to 30%
Passing 30 mesh and retained on 40 mesh	5 to 25%
Passing 20 mesh and retained on 30 mesh	5 to 15%
Passing 10 mesh and retained on 20 mesh	2 to 10%
Passing 8 mesh and retained on 10 mesh	0 to 5%
Total passing 80 mesh and retained on 200 mesh	20 to 40%
Total passing 20 mesh and retained on 40 mesh	12 to 45%

In very light traffic a coarser sand may be used with the approval of the Engineers, but in no case shall a sand be employed that contains less than a total of fifteen (15) per cent passing an 80-mesh sieve, such total to contain not more than five (5) per cent (calculated on the original sand) passing a 200-mesh sieve, or a mixture of seventy-five (75) per cent of sand of the character above specified and twenty-five (25) per cent of

stone screenings passing a one-quarter (¼) inch screen and retained on a 10-mesh screen, may be employed.

(N. B.) The above limits as to mesh composition are intended to provide for such permissible variations as may be rendered necessary by the available sources of supply and the character of the work to be done. The mesh composition and character of the sand may be varied, within the limits above specified, at the discretion of the Engineers, depending upon the kind of asphalt used and the traffic conditions.

Filler.—This shall be thoroughly dry limestone dust, or dust from other equally satisfactory stone, or Portland cement, the whole of which shall pass a 30-mesh-per-lineal-inch screen and at least 66 per cent of which shall pass a 200-mesh-per-lineal-inch screen. The surface mixture shall contain from 6 to 20 per cent of this filler, depending upon the kind of sand and asphalt used and the traffic conditions.

Samples.—One (1) pound samples of the refined asphalt, petroleum flux, and asphalt cement that the Contractor proposes to use in his work, together with a statement as to the source, character, and proportions of the materials composing them, must be handed in with his bid; and no contract shall be awarded to any bidder whose samples do not comply in every respect with these specifications. No asphalt other than that specified in his bid shall be used by any Contractor except with the written consent of the Engineers, and provided that it complies in all respects with the requirements of these specifications.

In addition to the samples submitted with the bid, other samples taken from and actually representative of the refined asphalt, petroleum flux, sand, filler, and binder stone to be used upon the structure shall be submitted to the Engineers before the use of such materials in the work is permitted. Except at the option of the Engineers, no work on binder or surface shall be commenced within three weeks from the date when such samples were submitted; and in no case shall they be used until they have been examined and approved by the Engineers. Whenever, during the course of the work, new deliveries of paving materials are received by the Contractor, samples of these shall at once be submitted to the Engineers; and their use in the work will not be permitted until they have been examined and approved by the said Engineers.

Asphalt Cement.

Preparation.—The asphalt cement shall be composed of refined asphalt—or asphalts and flux, where flux is required—of the character elsewhere herein specified, and it must be of a suitable degree of penetration.

The proper proportions of the refined asphalt (or asphalts) and flux shall be melted together at a temperature between 275 and 400 degrees F. and thoroughly agitated by suitable appliances until they are completely blended into a homogeneous asphalt cement. Thereafter, the asphalt cement must not be heated to a temperature exceeding 350 degrees F. If

the asphalt cement contains material that will separate by subsidence while it is in a molten condition, it must be thoroughly agitated before drawing from storage and while in use in the supply kettles. Excessive agitation with steam or air which will injure the cement must not be permitted.

The refined asphalt or asphalts and flux comprising the asphalt cement shall, when required, be weighed separately in the presence of the authorized Inspectors or agents of the Engineers.

Requirements.—The asphalt cement shall comply with the following requirements:

a. It shall be thoroughly homogeneous.

b. It shall have a penetration at 77 degrees F. of from 30 to 55 for heavy traffic and 55 to 85 for light traffic, depending upon the sand and asphalt used and the local climatic conditions.

c. It shall not flash below 350 degrees F. when tested in a closed oil-tester.

d. When twenty (20) grams of the asphalt cement are heated for five (5) hours at 325 degrees F. in a tin box two and one-quarter (2¼) inches in diameter and three-quarters (¾) of an inch deep, after the manner hereinafter prescribed, the loss shall not exceed five (5) per cent. by weight; and the penetration at 77 degrees F. of the residue left after such heating must not be less than one-half the penetration at 77 degrees F. of the original sample before heating.

e. Either the asphalt cement or its pure bitumen when made into a briquette (Dow mold) shall, at 50 penetration (77 degrees F.), have a ductility of not less than 30 centimetres at 77 degrees F.; the two ends of the briquette to be pulled apart at the uniform rate of 5 centimetres per minute.

When the asphalt cement as used has a penetration other than 50 at 77 degrees F., an increased ductility of 2 centimetres will be required for every five points in penetration above 50 penetration, and a corresponding reduction will be made below 50 penetration.

Binder.

Preparation.—The binder shall be composed of stone, or stone and sand, and asphalt cement of the character elsewhere herein specified and mixed in proper proportions. The stone, or stone and sand, and the asphalt cement shall be heated separately to such a temperature as will give, after mixing, a binder mixture of the proper temperature for the materials employed. The stone when used must be at a temperature between 225 and 350 degrees F. The asphalt cement and the stone shall be thoroughly mixed by machinery until a homogeneous mixture is produced, in which all the particles are thoroughly coated with asphalt cement.

Laying.—The binder mixture prepared in the manner above described shall be brought to the work in wagons covered with canvas or other

suitable material; and upon reaching the site it shall have a temperature between 200 degrees F. and 325 degrees F. The temperature of the binder mixture within these limits shall be regulated according to the temperature of the atmosphere and the working of the binder. On reaching the site it shall at once be dumped on the concrete base and then be deposited roughly in place by means of hot shovels, after which it shall be uniformly spread by means of hot iron rakes and then at once be thoroughly compacted by tamping or rolling. The thickness of the finished binder shall average one and a half (1½) inches; and not more than a forty (40) per cent variation from the average thickness specified will be permitted at any one spot. The upper surface of the finished binder shall be parallel to the established grade for the finished pavement. The surface after compression shall show at no place an excess of asphalt cement; for any spot showing such excess shall be cut out and replaced with other material. All binder that shows lack of bond or that is in any way defective or which may become broken up before it is covered with wearing surface must be taken up and removed from the site and replaced by good material properly made and laid in accordance with these specifications, at the expense of the Contractor. No more binder shall be laid at any one time than can be covered by one day's run of the paving plant on surface mixture. Binder when laid shall be followed and covered with wearing surface as soon as is practicable, in order to effect the most thorough bond between the binder and the wearing course. The binder course shall be kept as clean and as free from traffic as is possible under working conditions. If necessary, it must be swept off immediately before laying the wearing surface on it.

No binder shall be laid when, in the opinion of the Engineers, the weather conditions are unsuitable, or unless the concrete on which it is to be laid is free from pools of water and has set a sufficient length of time.

Requirements.—The finished binder must contain from four (4) to seven (7) per cent of bitumen soluble in cold carbon bisulphide, from fifteen (15) to thirty (30) per cent of material passing a 10 mesh screen, and from twenty (20) to fifty (50) per cent of material passing a one-half (½) inch screen, the percentage of bitumen to be regulated in accordance with the mesh composition and character of the mineral aggregate of the binder, and the percentage of material passing a 10 mesh screen to be regulated in accordance with the traffic conditions upon the roadway to be paved.

Wearing Surface.

Preparation.—The wearing surface shall be composed of sand, filler, and asphalt cement of the character elsewhere herein specified and mixed in proper and definite proportions by weight. The sand and the asphalt cement shall be heated separately to such a temperature as will give, after mixing, a surface mixture of the proper temperature for the materials

employed. The sand when used must be at a temperature between 275 and 375 degrees F. The asphalt cement when used must be at a temperature between 250 degrees F. and 350 degrees F. The various ingredients shall be brought together and mixed for at least one minute in a suitable apparatus until a homogeneous mixture is produced, in which all the particles are thoroughly coated with asphalt cement. The weights of all materials entering into the composition of the wearing surface shall be verified in the presence of Inspectors as often as may be required, and the Engineers or their representatives shall have access to all parts of the plant at any time.

Laying.—The surface mixture prepared in the manner above described shall be brought to the work in wagons covered with canvas or other suitable material, and upon reaching the site shall have a temperature between 230 degrees F. and 350 degrees F. The temperature of the surface mixture within these limits shall be regulated according to the temperature of the atmosphere, the working of the mixture, and the character of the materials employed. On reaching the site, it shall at once be dumped on a spot outside of the space on which it is to be spread. It shall then be deposited roughly in place by means of hot shovels, after which it shall be uniformly spread by means of hot iron rakes in such a manner that after having received its final compression by rolling, the finished pavement shall conform to the established grade. The thickness of the finished surface mixture shall average two (2) inches. Not more than a ten (10) per cent variation from the average thickness specified will be permitted in any one spot. Before the surface mixture is placed, all contact surfaces of curbs, man-holes, etc., must be well painted with hot asphalt cement. After raking, the surface mixture shall at once be compressed by rolling or tamping, after which a small amount of cement shall be swept over it, and it shall then be thoroughly compressed by a steam roller weighing not less than two hundred (200) pounds to the inch width of tread, the rolling being carried on continuously at the rate of not more than two hundred (200) square yards per hour per roller, until a compression is obtained which is satisfactory to the Engineers. Such portions of the completed pavement as are defective in finish, compression, or composition, or that do not comply in all respects with the requirements of these specifications, shall be taken up, removed, and replaced with suitable material, properly made and laid in accordance with these specifications, at the expense of the Contractor. Whenever so ordered by the Engineers, a space of twelve (12) inches next to the curb shall be coated with hot asphalt cement, which shall be ironed into the pavement with hot smoothing irons.

No wearing surface shall be laid when, in the opinion of the Engineers, the weather conditions are unsuitable, or unless the binder on which it is to be placed is dry. Excessive use of water on the steam roller when compressing the pavement will not be permitted. The finished pave-

ment must be well protected from all traffic by suitable barricades until it is in proper condition for use.

Requirements.—The finished pavement shall show upon analysis a mesh composition and bitumen contents within the following limits (sieves to be used in the order named):

Bitumen	9.5 to 13.5%
Passing 200 mesh	Not less than 10%
Passing 80 mesh	10 to 35%
Passing 50 mesh	4 to 35%
Passing 40 mesh	4 to 25%
Passing 30 mesh	4 to 20%
Passing 20 mesh	4 to 12%
Passing 10 mesh	2 to 8%
Passing 8 mesh	0 to 5%
Total passing 200, 100, and 80 mesh	Not less than 25%
Total passing 50 and 40 mesh	15 to 50%
Total passing 30, 20, and 10 mesh	10 to 35%

(N. B.) The minimum amount of bitumen shall be used only in mixtures containing the minimum total passing the 80 mesh. The percentage of bitumen must be increased above the minimum as the total passing the 80 mesh increases. On pavements subjected to very light traffic, when the Engineers have approved the use of a coarser sand or mixture than that specified for general use, the surface mixture must contain not less than six (6) per cent of mineral matter passing a 200 mesh sieve and not less than a combined total of eighteen (18) per cent passing the 200, 100, and 80 mesh sieves. The maximum amount of 200, 100, and 80 mesh material will be regulated according to the kind of sand and asphalt used and the traffic upon the structure on which the pavement is to be laid, subject to the maximum requirements elsewhere herein specified under sand and filler.

(N. B.) The above limits as to mesh composition and per cent of bitumen are intended to provide for such permissible variations as may be rendered necessary by the raw materials used and by the character of the work to be done. The composition of the wearing surface may be varied within the limits above specified at the discretion of the Engineers, depending upon the kind of sand. filler, and asphalt used and the traffic conditions.

Condition at Expiration of Guarantee.

In addition to the proper maintenance of the pavement during the period of guarantee, the Contractor shall, at his own expense, just before the expiration of the guarantee period, make such repairs as may be necessary to produce a pavement which shall:

a. Have a contour substantially conforming to that of the pavement as first laid and free from depressions of any kind exceeding three-eighths

(⅜) of an inch in depth as measured between any two points four (4) feet apart on a line conforming substantially to the original contour of the street.

b. Be free from cracks or depressions showing disintegration of the surface mixture.

c. Contain no disintegrated surface mixture.

d. Not have been reduced in thickness more than three-eighths (⅜) of an inch in any part.

e. Have a foundation free from such cracks or defects as will cause disintegration or settling of the pavement or impair its usefulness as a roadway.

Repairing.

Repairs, except as provided for below, shall in all cases be made by cutting out the defective binder and wearing surface down to the concrete and replacing them by new and freshly prepared binder and wearing surface made and laid in strict accordance with these specifications.

Whenever any defects are caused by the failure of the foundation, the pavement (including such foundation) shall be taken up and relaid with freshly prepared material made and laid in strict accordance with these specifications.

In all cases the surface of the finished repair shall be at the grade of the adjoining pavement and in accordance with the contour of the roadway.

The surface heater method of repairing may be used only in those cases where the repairs are not rendered necessary by:

a. Failure of concrete.

b. Failure of the binder.

c. Failure caused by the disintegration of the lower portion of the wearing surface.

Whenever the surface heater method is employed, all defective surface shall be removed before replacing it with new material. In all cases the old surface shall be removed to a depth of not less than one-quarter inch; and the new surface must, when compressed, be not less than one-half in thickness. The heat shall be applied in such a manner as not to injure the remaining pavement. All burnt and loose material shall at once be completely removed, and, while the remaining portion of the old pavement is still warm, shall be replaced by new and freshly prepared wearing surface made and laid in strict accordance with these specifications.

With the written permission of the Engineers, not to exceed twenty (20) per cent of crushed old asphalt surface mixture of suitable character may be used in combination with the binder stone, provided that such mixture produces a binder complying in all respects with the requirements of these specifications.

Methods for Testing and Sampling.

The following methods are recommended as being sufficiently accurate for general use; but in cases of dispute the standard methods adopted by the American Society for Testing Materials must be employed:

Penetration Test.—Penetrations shall be taken by means of a penetrometer, which shall be so constructed as correctly to register in one-hundredths of a centimetre the depth to which a Robert Sharp's No. 2 needle will penetrate the sample under examination under a given load without appreciably retarding friction for a given time period.

For penetrations at 77 degrees F. the time period shall be five (5) seconds and the total weight operating on the needle shall be one hundred (100) grams, except in the case of flux where the time period is one (1) second and the total weight fifty (50) grams.

The samples to be tested should, preferably, be in circular tin boxes about two and one-quarter (2¼) inches in diameter and about three-quarters (¾) of an inch deep (2-ounce Gill-style can, obtainable from the American Can Company). Where very soft materials are to be tested or penetrations are to be taken at 100 degrees F. or 115 degrees F., a tin not less than two (2) inches deep and having the same diameter specified above should be used.

All samples shall be melted at a temperature just high enough to render them liquid (250 to 300 degrees F.), and shall then be thoroughly stirred until homogeneous and free from air bubbles. After cooling sufficiently in the air at laboratory temperature they must be immersed for at least thirty (30) minutes in water maintained at the temperature at which the test is to be made (77 degrees F.). During testing, the sample shall be accurately maintained at the temperature specified.

The average of from three (3) to five (5) tests which must not differ more than five (5) points (five-hundredths (0.05) of a centimetre) between maximum and minimum shall be taken as the penetration of the sample, the needle being wiped off with a dry cloth after every determination.

(N. B.) This test measures the consistency of the material under examination. Its limits of accuracy may be considered as being within five (5) per cent of the reading obtained (above or below).

Ductility Test.—This test is usually first made on the asphalt cement itself. If this fails to show the required ductility, the pure bitumen must be extracted and tested. The proper methods for obtaining the pure bitumen vary with the asphalt being examined and are too lengthy for description here. (See *Proceedings* of American Society for Testing Materials, vol. 9, pages 594–9.)

The moulding of the briquette may be done as follows:

The mould should be placed upon a brass plate. To prevent the asphalt from adhering to the plate and the inner side of the two removable pieces of the mould, they should be well amalgamated. The differ-

ent pieces of the mould should be held together in a clamp or by means of an India rubber band. The material to be tested is poured into the mould while in a molten state, a slight excess being added to allow for shrinkage on cooling. After the briquette is nearly cool, it is smoothed off level by means of a heated palette knife. When cooled, the clamp is taken off and the two side pieces removed, leaving the briquette of asphalt firmly attached to the two ends of the mould, which thus serve as clips. The briquette should be immersed in water maintained at the required temperature for at least thirty (30) minutes or until the whole mass of bitumen is at 77 degrees F. It is then pulled apart at the required rate of speed in a suitable machine, the briquette being entirely immersed in water maintained at 77 degrees F. during the entire operation of pulling. Any pieces of dirt, wood, or extraneous matter in the briquette may cause the fracture of the fine thread before the true maximum ductility of the material under examination has been reached. Great care should be observed, therefore, to avoid the presence of such foreign matter in the bitumen when it is poured into the mould. The average of at least two tests shall be recorded as the ductility of the sample under examination. These tests must not differ more than twenty (20) per cent from their average.

(N. B.) This test measures approximately the cementing value of a bitumen, but is not necessarily a measure of the relative cementing value of different bituminous materials or the same bituminous material at different penetrations. Its limits of accuracy may be considered as being within twenty (20) per cent of the reading obtained (above or below).

Determination of Total Bitumen in Refined Asphalts and Asphalt Cements.—One to two grams of the sample shall be weighed into a tared 200 c.c. wide-mouth Erlenmeyer flask and covered with 100 c.c. of chemically pure carbon bisulphide. Agitate until all lumps disappear and nothing adheres to the bottom of the flask. Cork and allow to stand fifteen (15) minutes. Filter off on a Gooch crucible with asbestos felt or a weighed filter paper and wash until the washings come through practically colorless. Dry the flask and filter at 250 degrees F. Evaporate the filtrate containing the bitumen, burn to an ash and add to the residue on the filter.

(N. B.) The limits of accuracy of this test as applied to bitumens containing considerable proportions of non-bituminous matter may be considered as being within one-half (½) per cent above or below the result obtained. In practically pure bitumens one-quarter (¼) per cent above or below is the ordinary limit of accuracy.

Determination of Bitumen Soluble in Carbon Tetrachloride.—One gram of the sample shall be weighed into a tared 200 c.c. wide mouth Erlenmeyer flask and covered with 100 c.c. of chemically pure carbon tetrachloride. Agitate until all lumps disappear and nothing adheres to the bottom of the flask. Cork and allow to stand eighteen (18) hours in the dark. Filter off on a Gooch crucible with asbestos felt or a weighed

filter paper and wash until the washings come through practically colorless, using not less than 100 c.c. of fresh solvent. Dry the filter at 250 degrees F.

(N. B.) The amount of bitumen insoluble in carbon tetrachloride is indicative of whether or not decomposition has been produced by improper heat treatment. The limits of accuracy of this test may be considered as being within one-half (½) per cent above or below the result obtained.

Volatilization Test.—Twenty (20) grams of the sample shall be placed in a weighed tin box two and one-quarter inches in diameter and three-quarters of an inch high (two-ounce Gill-style can, obtainable from the American Can Company) and heated five (5) hours at 325 degrees F. The heating shall be done in a ventilated oven, which shall have reached the temperature specified before the introduction of the samples and which is maintained within two (2) degrees of that temperature throughout the test. The tin can should be insulated by a sheet of asbestos or other material from direct metallic contact with the sides or walls of the oven. The bulb of the thermometer should be immersed in a control bath immediately alongside of the sample being tested, the container and the method of insulation being the same in both cases.

(N. B.) This test indicates the extent to which bitumens in the course of time lose their more volatile hydrocarbon constitutents and the hardening resulting from volatilization and chemical change. It may be considered as an accelerated exposure test. Its limits of accuracy cannot be definitely stated, owing to the widely varying results obtained by the use of different types of ovens and failure carefully to observe all the conditions prescribed. When carefully conducted according to the above directions, a test showing six (6) per cent loss should be considered as passing a specification calling for not over five (5) per cent loss.

Flash Test.—The flash test shall be made in a circular tin can about two and one-quarter (2¼) inches in diameter and about one and three-eighths (1⅜) inches deep (3 ounce Gill-style, American Can Company), provided with a suitable transparent cover of mica, or glass, etc. This cover shall be provided with two apertures for the insertion of the thermometer and test flame. The aperture for the thermometer shall be three-eighths (⅜) of an inch in diameter and shall be centrally located. The aperture for the test flame shall be triangular in shape, measuring one-half (½) inch on the base and three-quarters of an inch in height. The base shall coincide with the rim of the can. A thermometer approximately fifteen (15) inches long, graduated in single degrees, shall have its bulb completely immersed in the material being tested. It shall not touch the bottom of the can, but shall be suspended in the proper position. The can shall be filled with the material to be tested so as to leave a one-half (½) inch vapor space when melted. The material shall be heated at the rate of ten degrees F. a minute, and the test flame shall be applied every five degrees F. after a temperature of 300 degrees F.

has been reached. No correction for emergent stem shall be made. The test flame shall be one-eighth (1/8) of an inch long, and shall be dipped in just below the surface of the cover and then immediately withdrawn.

(N. B.) This test indicates the temperature at which inflammable vapors are given off in an enclosed space. It supplements the volatilization test and guards against the use of a material containing too large an amount of volatile hydrocarbons. Its limit of accuracy may be considered as being five (5) degrees above or below the reading obtained.

Specific Gravity Test.

a. Fluid materials: The specific gravity of fluid materials shall be taken in the usual way in a picnometer at 77 degrees F.

b. Viscous fluid and semi-solid materials: The specific gravity of these materials shall be taken in a cylindrical, weighing-bottle picnometer.

c. Hard solid materials: The specific gravity of hard, solid materials shall be taken by the displacement method.

Determination of Bitumen Contents and Mesh Composition of Binder.

Weigh out from 350 to 500 grams of the binder and extract the bitumen from it in a centrifugal extractor or suitable continuous hot extractor, using chemically pure carbon bisulphide as a solvent for the bitumen. Follow the same general method for the drying and sifting of the mineral aggregate as described in the method for analyzing surface mixtures. The sieves to be used are as follows:

1¼-inch, 1-inch, ¾-inch, and ½-inch circular openings, and 10-mesh.

(N. B.) The limits of accuracy of this test are as follows:

For bitumen contents, three-tenths (3/10) per cent above or below the result obtained. For mesh composition, ten (10) per cent of the result obtained (above or below).

Determination of Bitumen Contents and Mesh Composition of Surface Mixtures.

The sample of surface mixture should be heated to about 300 degrees F. until soft, and ten to twenty grams of it should be weighed on to a tared S. & S. filter paper No. 595, 11 cms. in diameter. The filter paper and contents should be placed in a funnel and washed with chemically pure carbon bisulphide until the washings run through practically colorless. Dry the filter paper and residue at 250 degrees F. for one-half (½) hour. Open the filter paper carefully and remove the mineral aggregate. Scrape off the dust adhering to the paper as thoroughly as possible with a blunt palette knife and add it to the mineral aggregate. Evaporate the filtrate containing the bitumen, burn the bitumen, add the filter paper to it and burn to an ash. Add the ash to the mineral aggregate previously removed from the filter paper and weigh. The difference between the weight of surface mixture originally taken and the combined weight of

the ash and residue is considered as the weight of bitumen in the sample. The combination of ash and residue is then sifted through the following sieves (in the order named) and the percentages of the various sized particles calculated:

200, 100, 80, 50, 40, 30, 20, 10, and 8.

Sifting shall be continued on each sieve until less than one (1) per cent passes through the sieve during the last minute of sifting.

If desired, the surface mixture may be extracted in a centrifuge or in any suitable form of extractor with hot chemically pure carbon bisulphide, and the combined ash from the extracted bitumen and the mineral aggregate sifted as above.

(N. B.) The limits of accuracy of this test are as follows:

For bitumen contents, three-tenths ($\frac{3}{10}$) per cent above or below the result obtained. For mesh composition, ten (10) per cent of the result obtained (above or below).

Samples.

Samples should be put in clean, dry containers, preferably tin boxes or cans. The following amounts of the different materials are required for tests:

Binder stone	5 pounds
Filler	½ pound
Sand	1 pound
Refined asphalt	1 pound
Asphalt cement	1 pound
Flux	1 pound

Method of Sampling.

Extreme care should be taken in every case to obtain a sample which is truly representative of the material to be examined. The particular precautions to be observed in each case are given below:

Binder Stone.

A sufficient number of five-pound samples to be taken from different parts of the pile. These should be thoroughly mixed together and reduced by quartering to the desired size.

Filler.

A sample should be taken from several bags, and the various samples should be mixed.

Sand.

Samples should be taken from the interior of the pile where the sand is damp. A sufficient number of one-pound samples are to be taken from different parts of the pile. These should be thoroughly mixed together and reduced by quartering to the desired size.

Refined Asphalt and Asphalt Cement.

In barrels: At least one sample should be taken from each batch. It should be secured at sufficient depth below the surface to insure obtaining representative material free from all dirt or other extraneous matter.

In tank cars: The contents of the tank should be heated until completely liquid throughout. It shou'd then be agitated and thoroughly mixed by means of air or steam, after which the sample may be taken in any convenient manner.

In kettles: The contents of the kettles must be completely liquid and thoroughly agitated previous to and during sampling. The sample may be taken from the pipe through which the material is delivered to the mixer or by means of a clean dipper.

Flux.

The directions given for sampling refined asphalt and asphalt cement apply to this material, except that under ordinary conditions it is not necessary to agitate the contents of the tank car.

Surface and Binder Mixtures.

Samples should, preferably, be taken on the structure after the mixture has been shoveled and raked. Samples taken from the plant shall be obtained from the wagons, special care being observed to avoid material from the top of the load or which appears to vary from the average. Samples should be pressed between sheets of paper and trimmed while hot to a convenient size.

P. 136. *Bitulithic Pavement*

Description.—On a properly prepared concrete base, as shown on the drawings, shall be laid the wearing surface or pavement proper, which shall be composed of carefully selected, tough, sound, hard, crushed limestone, mixed with bitumen and laid as follows:

After heating the stone in a rotary mechanical dryer to a temperature of about 280 degrees Fahrenheit, it shall be elevated and passed through a rotary screen, having six or more sections with varying sized openings, the maximum of which shall be 1¾ inches, and the minimum of which shall be one-tenth (1/10) of an inch in diameter. The several sizes of stone thus separated by the screen sections shall pass into a bin containing six sections or compartments. From this bin the stone shall be drawn into a weigh-box resting on a scale having seven beams. The stone from each bin is accurately weighed in the proportion which has been previously determined by laboratory tests to give the best results; that is, the most dense mixture of mineral aggregate, and one having inherent stability. From the weigh-box, each batch of mineral aggregate, composed of differing sizes accurately weighed as above, shall pass into a "twin pug" or other approved form of mixer. In this mixer shall

be added a sufficient quantity of Warren's Puritan Brand Bituminous Water-proof cement, varied from No. 19 to No. 24, to suit the stone used—or other similar compound acceptable to the Engineers—in sufficient quantity to coat thoroughly all the particles of stone and to fill all voids in the mixture. The bituminous cement shall, before mixing with the stone, be heated to between 200 and 250 degrees Fahrenheit. The amount for each batch shall be accurately weighed, and it shall be used in such proportion as has been previously determined by laboratory examination to give the best results and to fill the voids in the mineral aggregate. The mixing shall be continued until the combination is a uniform bituminous concrete. In this condition it shall be hauled to the street, and there spread on the prepared foundation to such depth that, after thorough compression with a steam roller, it shall have a thickness of two (2) inches. The proportioning of the varying sizes of stone and bituminous cement shall be such that the compressed mixture shall, as closely as practicable, have the solidity and density of solid stone.

Surface Finish.—After rolling the wearing surface, there shall be spread over it, while it is still warm, a thin coating of Warren's Quick Drying Bituminous Flush Coat Composition, or other similar compound acceptable to the Engineers, by means of a suitable flush-coat spreading-machine, so designed as to spread quickly over the surface a uniform thickness of the said Flush Coat Composition. This spreading-machine shall be provided with a flexible spreading band and an adjustable device for regulating, to any desired amount, the quality and uniformity of the composition to be spread. On grades of over 4 per cent a mineral Flush Coat may be used in place of the liquid Flush Coat.

While the Flush Coat Composition is still warm, there shall be spread over it, in at least two coats, fine particles of hot crushed stone, in sufficient quantity completely to cover the surface of the pavement. The stone chips shall be spread by means of a suitable stone-spreading machine, so designed as to provide a storage receptacle of at least five (5) cubic feet capacity, and rapidly and uniformly to cover the surface of the pavement with the desired quantity of stone. This spreading machine shall be provided with an adjustable attachment for regulating uniformly the quantity of stone spread at each operation. The hot chips shall be immediately and thoroughly rolled into the surface until it has become cool. The purposes of the Flush Coat Composition and the fine particles of hot crushed stone are not only to fill any unevenness in the surface, but also to make the said surface waterproof and gritty, thus providing a good foothold for horses. The size of the stone chips is to be subject to special direction by the Engineers; and they are to be of the same quality as the stone specified for the wearing surface.

The roller used for compressing the wearing surface and for rolling the stone chips shall be operated by steam power, and shall give a weight pressure of not less than 250 pounds per lineal inch of roller.

Each layer of the work shall be kept free from dirt, so that it will unite with the succeeding layer. The amount of bituminous cement to be used for coating the heated stone for the wearing surface shall be varied as the Engineers may direct, in order to suit the varying volume of voids in the aggregate. The bituminous composition shall be free from water, petroleum oil, water-gas, tar, or inferior process tars; and it shall be especially refined in order to remove the light volatile oils and other matter susceptible to atmospheric influences. The cut-back process shall not be used in making the bituminous cement.

If the fine-crushed stone used does not provide the best proportions of fine-grained particles, these must be supplied by the use of hydraulic cement, pulverized stone, or very fine sand, as the Engineers may direct; but the amount thereof shall in no case exceed fifteen (15) per cent of the total mass.

V. 137. *Brick Paving*

In the following example, Portland cement grout, coal-tar paving-pitch, and asphalt joint fillers are included; but usually only one kind will be used in any one specification.

Example

Character of Brick.—All brick must be strictly No. 1 pavers of the sizes commercially known as "vitrified block," and "brick," the widths of which must not vary more than one-eighth (1/8) of an inch. They must be thoroughly annealed, tough, and durable, regular in size and shape, and evenly burned.

When broken, the brick shall show a dense, stone-like body, free from lime, air-pockets, cracks, or marked laminations. They must not be fire flashed, smoked, or treated in any manner tending to give artificially a uniform color outside. Kiln marks must not exceed three-sixteenths (3/16) of an inch in depth and one edge at least shall show but slight kiln marks. All brick so distorted in burning as to lay unevenly in the pavement shall be rejected.

The standard size of brick shall be two and one-half (2½) inches in width, four (4) inches in depth, and eight and one-half (8½) inches in length; and the standard size of block three and one-half (3½) inches in width, four (4) inches in depth, and eight and one-half (8½) inches in length. They shall not vary from these dimensions to exceed one-eighth of an inch in width and depth, and not more than one-half (½) inch in length. If the edges of the brick are rounded, the radius shall not exceed three-sixteenths (3/16) of an inch. Only brick with raised lugs on one side not to exceed one-fourth (¼) of an inch in height shall be used.

Inspection.—All brick shall be subjected to thorough inspection before and after laying and rolling, and all rejected material shall be immediately removed from the site.

Factory inspection of brick including the rattler test, shall be made, if,

in the judgment of the Engineers, it be expedient. This test shall, however, in no wise prevent further tests of the brick after they have been received upon the work, if, in the judgment of the Engineers, such is warranted.

Delivery of Brick.—The brick shall be hauled, carefully unloaded by hand, and neatly piled on the walks or outside of the curbs before the grading is finished; and in laying shall be carried from there to the pavement.

Rattler Test for Block Size.—The brick shall not lose of their weight more than 22 per cent after being submitted to the following tests, provided, however, that brick from any one factory and used in any one structure shall not vary more than eight (8) points.

Samples of brick of uniform shape and appearance shall be taken from each car tested (estimated at 10,000 brick). Brick having defects that would cull them shall not be used. Three grades of samples shall be tested—one of the softest, one of the medium, and one of the hardest burned. If all of the tests overrun the above percentage of loss, the car shall be rejected. If one or two of the tests overrun, another test of the said grade or grades shall be made. Should only one of these tests overrun the specified percentages of loss, the Contractor may cull the said grade, provided they do not exceed ten (10) per cent of the amount of brick in the car, and deliver the balance on the work. Otherwise the whole carload will be rejected.

In order to prevent the continued shipments of inferior brick, two cars of two separate shipments of any make of brick will be tested. Should they fail to meet the requirements stated above, the said make of brick will be rejected.

Number and Condition of Brick.—Ten (10) paving brick shall constitute the number to be used in a single test. The brick shall be thoroughly dried for at least three (3) hours in a temperature of one hundred (100) degrees Fahrenheit before testing.

Tests before Unloading.—The Contractor shall notify the Engineers of the location and car number of each carload of brick received, so that samples, if deemed necessary, may be taken and tested; and no brick shall be delivered at or adjacent to the site until a written statement has been received from the Engineers or their authorized representative, that they have been superficially inspected or have passed the required tests. Decision relative to each carload will be made within twenty-four (24) hours of notice. Permission to deliver brick on the line of work shall not be considered a final acceptance in any respect.

Making the Rattler Test.

The machine shall be of good mechanical construction, self-contained, shall conform to the following details of material and dimensions, and shall consist of barrel, frame, and driving mechanism as herein described.

The Barrel.—The barrel of the machine shall be made up of the heads, headliners, and staves.

The heads shall be cast with trunnions in one piece. The trunnion bearings shall not be less than two and one-half (2½) inches in diameter or less than six (6) inches in length.

The heads shall not be less than three-fourths (¾) of an inch thick nor more than seven-eighths (⅞) of an inch. In outline they shall be a regular fourteen (14) sided polygon inscribed in a circle twenty-eight and three-eighths (28⅜) inches in diameter. The heads shall be provided with flanges not less than three-fourths (¾) inch thick and extending outward two and one-half (2½) inches from the inside face of head to afford a means of fastening the staves. The flanges shall be slotted on the outer edge, so as to provide for two (2) three-fourths (¾)inch bolts at each end of each stave, said slots to be thirteen-sixteenths (13/16) inch wide and two and three-fourths (2¾) inches from centre to centre. Under each section of the flanges there shall be a brace three-eighths (⅜) inch thick and extending down the outside of the head not less than two (2) inches. Each slot shall be provided with a recess for the bolt head, which shall act to prevent the turning of the same. There shall be for each head a cast iron headliner one (1) inch in thickness and conforming to the outline of the head, but inscribed in a circle twenty-eight and one-eighth (28⅛) inches in diameter. This liner or wear plate shall be fastened to the head by seven (7) five-eighths (⅝) inch cap screws through the head from the outside. These wear plates, whenever they become worn down one-half (½) inch below their initial surface level at any point of their surface, must be replaced with new. The metal of which these wear plates are to be composed shall be what is known as hard machinery iron and must contain not less than one (1) per cent of combined carbon. The faces of the polygon must be smooth and must give uniform bearing for the staves. To secure the desired uniform bearing the faces of the head may be ground or machined.

The Staves.—The staves shall be made of six (6) inch medium steel structural channels twenty-seven and one-fourth (27¼) inches long and weighing fifteen and five-tenths (15.5) pounds per lineal foot.

The channels shall be drilled with holes thirteen-sixteenths (13/16) of an inch in diameter, two (2) in each end, for bolts to fasten same to head, the centre line of the holes being one (1) inch from either end and one and three-eighths (1⅜) inches either way from the longitudinal centre line.

The spaces between the staves will be determined by the accuracy of the heads, but shall not exceed five-sixteenths (5/16) of an inch. The interior or flat side of each channel must be protected by a lining or wear plate three-eighths (⅜) inch thick by five and one-half (5½) inches wide by nineteen and three-fourths (19¾) inches long. The wear plate shall consist of a medium steel plate and shall be riveted to the channel by three

(3) one-half (½) inch rivets, one of which shall be on the centre line both ways and the other two on the longitudinal centre line and spaced seven (7) inches from the centre each way. The rivet holes shall be countersunk on the face of the wear plate, and the rivets shall be driven hot and chipped off flush with the surface thereof. These wear plates shall be inspected from time to time, and, if found loose, shall be at once re-riveted; but no wear plate shall be replaced by a new one except as the whole set is changed. No set of wear plates shall be used for more than one hundred and fifty (150) tests under any circumstances. The record must show the date when each set of wear plates goes into service and the number of tests made upon each set.

The staves when bolted to the heads shall form a barrel twenty (20) inches long, inside measurement, between wear plates. The wear plates of the staves must be so placed as to drop between the wear plates of the heads. These staves shall be bolted tightly to the heads by four (4) three-fourths (¾)-inch bolts. Each bolt shall be provided with lock nuts and shall be inspected at not less frequent intervals than every fifth (5th) test, and all nuts shall be kept tight. A record shall be made after each such inspection, showing in what condition the bolts were found.

The Frame and Driving Mechanism.—The barrel shall be mounted on a cast-iron frame of sufficient strength and rigidity to support the same without undue vibration. This shall rest on a rigid foundation, and shall be fastened thereto by bolts at not less than four points.

The barrel shall be driven by gearing in which the ratio of driver to driven shall not be less than one (1) to four (4). The countershaft upon which the driving pinion is mounted shall not be less than one and fifteen-sixteenths ($1^{15}/_{16}$) inches in diameter, with bearings not less than six (6) inches in length and belt driven; and the pulley shall not be less than eighteen (18) inches in diameter and six and one-half (6½) inches in face. A belt of six (6)-inch, double-strength leather, properly adjusted so as to avoid unnecessary slipping, shall be used.

The Abrasive Charge.—The abrasive charge shall consist of two sizes of cast-iron spheres. The larger size shall be three and seventy-five hundredths (3.75) inches in diameter when new, and shall weigh then approximately seven and five-tenths (7.5) pounds (3.40 kilos) each. Ten shall be used.

These shall be weighed separately after each ten tests, and if the weight of any large shot falls to seven (7) pounds (3.175 kilos) it shall be discarded and a new one substituted; provided, however, that all of the large shot shall not be discarded and new ones substituted at any single time, and that so far as possible the large shots shall compose a graduated series in various stages of wear.

The smaller size sphere shall be, when new, one and eight hundred and seventy-five thousandths (1.875) inches in diameter, and shall weigh not to exceed ninety-five hundredths (0.95) of a pound (0.430 kilo) each.

Of these spheres so many shall be used as will bring the collective weight of the large and small spheres most nearly to three hundred (300) pounds, provided that no small sphere shall be retained in use after it has been worn down so that it will pass a circular hole one and seventy-five hundredths (1.75) inches in diameter drilled in a cast-iron plate one-fourth (¼) inch in thickness, or if it weigh less than seventy-five hundredths (0.75) of a pound (or 0.34 kilo.). Further, the small spheres shall be tested after every ten tests, by passing them over such an iron plate drilled with such holes, or by weighing, and any which pass through the holes or fall below the specified weight shall be replaced by new spheres; provided, further, that all of the small spheres shall not be rejected and replaced by new ones at any one time, and that so far as possible the small spheres shall compose a graduated series in various stages of wear.

If at any time any sphere is found to be broken or defective it shall at once be replaced.

The iron composing these spheres shall have a chemical composition within the following limits:

Combined carbon	Not less than 2.50 per cent
Graphite carbon	Not more than 0.10 per cent
Silicon	Not more than 1.00 per cent
Manganese	Not more than 0.50 per cent
Phosphorus	Not more than 0.25 per cent
Sulphur	Not more than 0.08 per cent

For each new batch of spheres used the chemical analysis must be furnished by the maker, or be obtained by the user, before introduction into the charge; and unless the analysis meets the above specifications, the batch of spheres shall be rejected.

The Test.—The rattler shall be rotated at a rate of not less than 29½ nor more than 30½ revolutions per minute, and 1,800 revolutions shall constitute the standard test. A counting machine shall be attached to the rattler for counting the revolutions.

A margin of not to exceed ten revolutions will be allowed for stopping. In case a charge is allowed to run several minutes beyond its proper termination, and the loss incurred is still within the prescribed limits, then the test shall not be discarded, but the fact shall be entered on the record.

Stopping and Starting.—Only one start and stop per test is regular and acceptable. If from accidental causes a test is stopped and started twice extra, and the loss exceeds the maximum permissible, the test shall be disqualified, and another shall be made.

The Results.—The loss shall be calculated in percentage of the original weight of the dried brick composing the charge. In weighing the rattled brick, any piece weighing less than one (1) pound shall be rejected.

The Record.—The operator shall keep an official book, in which the alternate pages are perforated for removal. The record shall be kept in duplicate, by use of a carbon paper between the first and second sheets, and when all entries are made and calculations are completed, the original record shall be removed and the carbon duplicate preserved in the book. All calculations must be made in the space left for that purpose in the record blank and the actual figures must appear. The record must bear its serial number and be filled out completely for each test; and all data as to dates of inspections, weighing of shot, and replacement of wornout parts must be carefully entered, so that the record remaining in the book shall constitute a continuous one. In event of further copies of a record being needed, they may be furnished on separate sheets, but in no case shall the original carbon copy be removed from the record book.

The blank form upon which the record of all official brick tests is to be kept and reported is as follows:

REPORT OF STANDARD RATTLER TEST OF PAVING BRICK

Identification Data (Serial No.)

Name of firm furnishing sample..
Name of the firm manufacturing sample..................................
Bridge or job which sample represents..................................
Brands or marks on the brick...
Quantity furnished............................Drying treatment............
Date received.................................Date tested.................
Length.................Breadth................Thickness...................

Standardization Data

Number of charges tested since last inspection.........................
....
....
Weight of charge (after standardization)...............................
Condition of locknuts on staves..
Condition of scales..
Ten large spheres..
Small spheres..
Total..
Number of charges tested since stave linings were renewed..............
Repairs (Note any repairs affecting the condition of the barrel)......

Running Data

Time readings—Hour............. Minutes............. Seconds.............
Revolution counter readings.............. Running notes, stops, etc...........
Beginning of test..
Final reading..

Weights and Calculations

Initial weight of ten bricks...
Final weight of same...
Loss of weight....................... Percentage loss....................
Note: (The calculations must appear)...................................
....
....

Number of broken bricks and remarks on same.................................

I certify that the foregoing test was made under the specifications of.............
and is a true record.

Signature of tester.......................

Date................................ Location of Laboratory.............

....

....

Construction of the Pavement.

Foundation.—The foundation shall be a concrete base as shown on the drawings.

Sand Cushion.—Over the foundation, which must be thoroughly cleaned, shall be spread to a uniform depth of one and one-half (1½) inches (after rolling) a cushion of clean, sharp sand, free from foreign matter, except that it may contain not to exceed 10 per cent of loam. The sand must be fairly well graded from one-quarter (¼) inch to that which will be retained on No. 50 standard mesh sieve. The word "sand" includes broken stone or slag meeting the specified grading.

The cushion shall be carefully shaped to a true cross-section of the roadway by means of a template having a steel-faced edge, covering at least one-half (½) the width of the brickwork, and so fitted with rollers as to be easily drawn on the curb and guide timbers or rail.

Template.—The template shall be built in substantial accordance with the plans.

Guide Timbers.—Guide timbers shall be one and one-half (1½) inches by four (4) inches by sixteen (16) feet, dressed on two sides, laid to a true surface in the centre of the street, and also next to the curb if the curb cannot be used.

Shaping Cushion.—Before shaping the cushion, one-half (½) inch strips shall be laid on the curb and guide timbers, or rail, and the template shall be drawn over the same, after which the one-half (½) inch strip shall be removed, and the cushion shall be slightly moistened and rolled over its entire surface with a hand roller. The roller shall not be less than thirty-six (36) inches in diameter or twenty-four (24) inches in width, and shall weigh not less than ten (10) pounds per inch of width. It shall have a handle twelve (12) feet in length. After rolling, the template shall be drawn over the curb and guide timbers or rail, to complete the cushion, which shall be prepared at least fifty (50) feet in advance of the brick laying.

Laying the Brick.—The brick shall be laid in straight lines on edge, at right angles to the curb. At intersections they shall be laid as directed. Brick shall be laid with the lug sides all in the same direction. Brick must be placed close together, both ends and sides, breaking joints at least three (3) inches. At every fourth course the brick shall be driven together to secure tight joints and straight courses, and all thick brick shall be removed. Brick shall be used with the best edge up. Broken,

chipped, or warped brick, not suitable to lay as a whole, may be used for batting.

When any section shall contain more than ten (10) per cent of culls, the brick shall be taken up and the cushion adjusted. Brick shall be laid from curb to curb, or from car track to curb.

No bats or broken brick shall be used except at curbs or at street car tracks. Batting for closures shall immediately follow the laying.

Joints shall be cut square with the top and sides of the brick, and must be kept clean and open to the bottom until filled as specified.

Street-Car Tracks.—Along the street-car tracks the brick must not be laid within one-quarter (¼) of an inch of the rail, and when rolled shall be one-quarter (¼) inch below the top of the rail.

The space between the web of the rail and the brick shall be filled with cement mortar, consisting of two (2) parts of sand and one (1) part of Portland cement. The mortar shall be in proper condition and the edge shall be constructed to a straight line before the brick are laid.

Expansion Joints for Cement Grout Filler.—Expansion joints shall be placed parallel with and at each of the curb lines, and shall be one and one-half (1½) inches in width. The joints shall be made by placing together on edge, parallel with the curb, two wedge-shaped strips six (6) inches in width, and dressed on two faces. The strip next to the curb shall be one (1) inch wide on top, beveled to a thickness of one-half (½) inch at the bottom, and the strip next to the brick shall be of the same dimensions and placed in a reverse position. The brick shall be laid lightly against said strips. Soon after the pavement has been grouted and the cement filler has set, and the pavement is in all other respects finished, the strips shall be removed, the joints thoroughly cleaned out, and immediately completely filled with a bituminous filler composed of a material which, when penetrated by a No. 2 needle under a weight of 200 grams for one (1) minute at a temperature of 32° Fahr., will have a penetration of not less than 20, and when penetrated by a No. 2 needle under 50 grams for five (5) seconds in a temperature of 115° Fahr., will not have a penetration of over 100.

A premoulded expansion strip made of a material unaffected by the action of water or street liquids may be used along each curb line, if it meets all the requirements for the joint filler herein specified. These strips shall not be less than three quarters (¾) of an inch in width for a thirty (30) foot street or under, increasing proportionately in width to one and one-half (1½) inches in width for a fifty (50) foot street or over.

Rolling.—After the brick in the pavement have been passed for rolling and the surface swept clean, the pavement shall be rolled with a roller weighing not less than three (3) nor more than five (5) tons, in the following manner: The brick next the curb shall be tamped with a hardwood tamper to the proper grade. The rolling shall then commence near

the curb at a very slow pace, and shall continue back and forth toward the centre, until the centre of the roadway is reached; then, passing to the opposite curb, it shall be repeated in the same manner to the centre of the roadway. After this first passing of the roller the pace may be quickened and the rolling continued until the brick pavement has a smooth surface. The pavement shall then be rolled transversely at an angle of forty-five (45) degrees from curb to curb, repeating the rolling in the opposite forty-five (45) degree direction. Before and after this transverse rolling has taken place, all broken or injured brick must be taken up and replaced with perfect ones. The substitute brick must be brought to the true surface by tamping.

After final rolling, the pavement shall be tested with a ten (10) foot straight edge, laid parallel with the curb, and any depression exceeding one-quarter (¼) of an inch must be taken out. If necessary, the pavement shall be again rolled.

Portland Cement Grout Filler.—The filler shall be composed of one part each of fine, clean, sharp sand and Portland cement. The latter shall comply with the standard requirements given elsewhere in this specification.

The sand shall be clean and sharp, fairly well graded from that passing a 20-standard sieve to that retained on a 100-standard sieve. Sand shall be measured in a box having the same cubical contents as one sack of cement.

Before any grouting is done, a sufficient amount of cement and an equal amount of sand to complete the work prepared for grouting at that time, but not to exceed one-half (½) day's run, shall be thoroughly mixed dry until the mass assumes a uniform color. From this mixture an amount not exceeding two (2) cubic feet shall be taken and placed in the grouting box, and enough clean water shall be added to obtain a grout that will penetrate to the bottom of the brick. From the time the water is applied until all is removed and floated into the joints of the pavement, the mixture must be kept in constant motion. A mechanical mixer approved by the Engineers that will meet these requirements may be used after the dry mixture of sand and cement has been made. Before the grout is applied the brick shall be thoroughly wet by being gently sprayed.

The water shall be added to this dry mixture in a box preferably about four (4) feet eight (8) inches long, thirty (30) inches wide, and fourteen (14) inches deep, resting on legs of different lengths, so that the mixture will rapidly flow to the lower corner of the box, the bottom of which shall be about three (3) inches above the pavement. One box shall be used tor each fourteen (14) feet in width of roadway, and at least two (2) boxes must be used in all cases.

The grout shall be removed from the box with scoop shovels and applied to the brick in front of the sweepers, who shall rapidly sweep

it lengthwise of the brick into the unfilled joints, until the said joints are filled to within not more than one-half ($\frac{1}{2}$) inch of the top of the brick. After the grout has had a chance to settle into the joint and before the initial set develops, the balance of every joint shall be filled with a thicker grout, and, if necessary, refilled, until the joints remain full to the top.

After this application has had time to settle and before the initial set takes place, the pavement shall be finished to a smooth surface with a squeegee, or wooden scraper, having a rubber edge, which shall be worked over the brick at an angle therewith.

When completed and after the cement has received its initial set, the pavement shall be covered with a one-half ($\frac{1}{2}$) inch layer of sand, which shall be frequently sprinkled in warm weather. No travel shall be permitted on the pavement for a period of at least seven (7) days after grouting, or longer, as the Engineers may require on account of weather conditions.

Ample barricades and watchmen shall be provided by the Contractor for the proper protection to the grouting.

Coal-Tar Paving-Pitch Filler.—The joints or spaces between the bricks, and those between the bricks and the curb, railroad tracks, around manholes, etc., shall be filled with coal-tar paving pitch, which shall comply with the following requirements:

Physical Properties.—When in place in the pavement, it shall be of such character that it will adhere firmly to the paving brick and to the curb, and shall be sufficiently plastic to allow for the contraction and expansion of the pavement without developing cracks in the joints. The filler shall be such that it will retain its consistency under extreme temperature. It shall be proof against action by water and all acids and alkalies to which the pavement may be exposed. The free carbon shall not be less than 25 per cent, nor more than 40 per cent. The specific gravity shall not be less than 1.23 nor more than 1.30 at 60° Fahr.

Melting Point.—It shall have a melting point varying not more than 5° from 135° Fahr., determined by the cube method (hereinafter described.)

Method of Use.—The filler shall be heated and poured into the joints to the full depth thereof, at a temperature of not less than 300° Fahr., nor greater than 350° Fahr. All joints shall be completely filled at the top. The top dressing of sand shall be spread over the pavement immediately after the filler is applied and while it is still soft. In cold weather the sand shall be heated so as readily to bond with the pitch. Extra care shall be used at the gutters and around catch-basins, etc., effectually to prevent the leakage of water into the sub-roadway.

Test for Melting Point of Pitch Filler.—A clean-shaped one-half inch cube of the pitch is to be formed in a mould and suspended in a beaker so that the bottom of the pitch to be tested is one (1) inch above the

bottom of the said beaker. The pitch is to remain for five (5) minutes in water of a temperature of 60° Fahr. before heat is supplied. Heat is to be applied in such a manner that the temperature of the water is raised 9° Fahr. each minute. The temperature recorded by the thermometer at the instant the pitch touches the bottom of the beaker is to be considered the melting point.

Asphalt Filler.—The interstices of the brick shall be completely filled with an asphalt filler heated to a temperature of not less than 350° Fahr. nor more than 450° Fahr. This asphalt filler shall not contain pitch nor any part of coal tar. It shall contain at least ninety-eight (98) per cent of bitumen soluble in carbon bisulphide. It shall remain pliable at all temperatures to which it may be subjected as a street paving filler; it shall be absolutely proof against water and street liquids; it shall firmly adhere to the brick and be pliable rather than rigid. Care shall be exercised completely to fill all openings around street structures, and the street shall not be used for traffic until the filler is thoroughly set. A top dressing of sand shall be spread immediately after the filler is applied and while it is still soft.

The penetration shall conform to the following:

No. 2 needle, 5 sec., 100 grams at 77° Fahr., 25 to 60.
No. 2 needle, 1 min., 200 grams at 32° Fahr., not below 25.
No. 2 needle, 5 sec., 20 grams at 115° Fahr., not above 110.

Maintenance.—The period of guaranty shall be five (5) years. During the said period, whenever the surface of a vitrified brick pavement becomes uneven, holding water one-fourth (¼) of an inch or more in depth in a distance of four (4) feet or less, or when the pavement on embankments has settled over trenches existing previous to the completion of the pavement, then the brick shall be taken up and relaid to proper crown and grade.

Any brick which may be found soft, unsound, broken, or disintegrated, and all portions of the pavement which may have become rough by reason of the chipping or breaking of the edges of the brick, so as to produce joints exceeding one-half (½) inch at a point one-quarter (¼) inch below the surface of the brick, shall be removed, and properly replaced with sound material.

P. 138. *Catch-Basins*

At proper intervals, as indicated on the drawings, catch-basins are to be built for the collection of water, which is to be led to the ground from these or discharged into the river by down-spouts.

P. 139. *Down-Spouts*

Down-spouts of the sizes and quality indicated on the drawings are to be provided at the catch-basins. They are to be carried to the ground

or connected to the sewers wherever the Engineers so direct. In general, cast iron pipes are to be used in city streets, or wherever they are liable to receive injury, and either copper or the best quality of tin elsewhere.

V. 140. *Sidewalk Floors in General*

These should be described thoroughly in detail. Sometimes they are built of reinforced concrete or granitoid; at other times of untreated timber. Creosoted timber is seldom used for sidewalks, because the untreated is so much cheaper and because wooden sidewalks are easily renewed or repaired, almost without interference with traffic thereon; and furthermore, the creosote is very undesirable on a footwalk. Asphalt sidewalks are sometimes employed, but they are not as satisfactory as granitoid ones, and it is not likely that they will ever be called for.

The following are types of specifications for sidewalks of the two usual kinds:

P. 141. *Timber Sidewalk Floors*

The sidewalk floors are to be built of dressed timber in the most substantial and thorough manner practicable, in order to prolong their life to the utmost. Wherever timber comes in contact with other timber or with the steel work, it is to be thoroughly painted with hot asphalt. All holes of any kind which are bored in any of the timbers are to be thoroughly saturated with hot asphaltum; and all bolts and faces of washers which are to be placed in direct contact with the timber are to be warmed and dipped in a vat of the same material.

I. 142. *Granitoid Sidewalks*

The sidewalks are to be of reinforced granitoid .... (...) inches thick, as is indicated on the drawings. The top is to be brought to the exact surface required and finished smooth. The proportions for the granitoid are to be one (1) part of Portland cement, two (2) parts of clean, coarse, sharp sand, and three (3) parts of granite chips broken so small as to pass a one-half (½) inch iron ring.

P. 143. *Expansion Plates for Floors*

At all expansion points, the open spaces in the pavements or flooring are to be covered with steel plates fastened at one side and free to move at the other.

P. 144. *Concrete Sidewalks*

Concrete sidewalks on ground or embankments shall be constructed as follows:

The sidewalks shall not be built until the curbs are in place. Any soft or unsuitable material found in the sub-grade shall be removed and

the space filled with bank gravel, cinders, or other satisfactory material. The sub-grade shall be compacted and brought to correct elevation by rolling or tamping to the satisfaction of the Engineers. Concrete mixed as herein specified, of proportions one (1) part of cement, three (3) parts of sand, five (5) parts of broken stone or gravel to pass a two and one-half (2½) inch iron ring, shall be placed on the sub-grade, the entire thickness of slab, except the surface finish, being placed at one operation.

The upper portion of the sidewalk slabs, three-fourths (¾) of an inch thick, shall consist of one part of Portland cement to one and one-half (1½) parts of sand. It shall be placed and finished by floating before the mortar in the concrete composing the remainder of the slab has set.

I. 145. *Pavement Base and Curbs on Embankments*

The surface of ground or fill is to be thoroughly rolled and compacted. The rolling is to be done with a roller weighing not less than ten (10) tons, and it is to be continued until the ground shall be brought to conform to the finished grade, being .... (.....) inches lower than the same and parallel thereto. Concrete mixed as herein specified, in the proportion of one (1) part of cement, three (3) parts of sand, and five (5) parts of broken stone or gravel to pass a two and one-half (2½) inch iron ring shall be laid thereon to a depth of .... (.....) inches; and the entire thickness is to be placed at one operation.

The curbs on the street and embankment beyond the ends of the steel work are to be made of concrete as above specified, and finished on the exposed front side and the top with mortar, mixed in the proportion of one (1) part of cement to three (3) parts of sifted sand. The mortar is to be plastered inside the form immediately before the concrete is placed and the top finish is to be put on before the concrete sets hard. The curb is to be cut entirely through, making blocks not exceeding six (6) feet in length. All exposed surfaces shall be carefully finished by troweling to a smooth and even finish; and they must be left free from irregularities and depressions. The angle-iron guard, when called for by the plans, is to be placed as the curb is constructed; and it is to be maintained in position so to be exactly flush with the finished surface of the concrete.

P. ·146. *Macadam Pavement*

The surface of the roadway shall be excavated to the depth required by the Engineers, then rolled and compacted with a steam roller weighing not less than ten (10) tons; and, when thoroughly compacted to the satisfaction of the Engineers, it shall be left true to sub-grade, which will be twelve (12) inches below and parallel to the established cross-section of the street, as shown on the accompanying plans. Any soft or spongy ground shall be removed, and such excavation and other depressions as may appear shall be filled with dry earth or broken stone and rolled until

the whole surface is firm and solid, as the Engineers may direct. Whenever necessary, drain pipes shall be laid for the purpose of draining such portions of the sub-grade as the Engineers may deem to require such treatment. Such drains shall consist of first-class vitrified four (4) inch sewer pipe laid with open joints, the latter to be completely covered by wrapping-strips of canvas of sufficient width to prevent the earth filling from obstructing the joints. Drain tiles covered with broken stone may be used instead of the sewer pipes. The pipes or tiles shall be laid to such lines and grades as may be directed by the Engineers, not less than eighteen (18) inches below the finished sub-grade to be drained, and of sufficient depth elsewhere to reach the nearest possible outlet.

On the sub-grade thus prepared shall be spread a layer of crusher-broken limestone, which, when thoroughly compacted by rolling, to the satisfaction of the Engineers, shall be six (6) inches in depth. The stone in this layer shall be good, sound limestone, practically uniform in quality, as near an approach to a cube as possible, broken so that the greatest dimension shall not exceed three and one-half (3½) inches and shall not be less than two (2) inches, and free from dust, dirt, and screenings. All stones that are wedge-shaped, or which do not approach uniformity of measurement, shall be taken from the roadbed; and no stones shall be allowed to remain which are not sound, strong, and equable in size and quality of material. Should any unevenness or depressions appear in the rolled surface of this layer, they shall be filled with broken stone and re-rolled until a firm, thoroughly compact, even surface is obtained that is six (6) inches below and parallel to the established finished surface cross-section of the pavement.

Upon the above-described stone foundation will be placed a layer of broken limestone of the same quality as above specified and of sufficient depth to bring this layer to a uniform finish, free from irregularities and depressions, to two (2) inches below and parallel to the established cross-section. The stone in this layer shall be broken so that the greatest dimension shall not exceed two and one-half (2½) inches and shall not be less than one and one-quarter (1¼) inches; and of this material from sixty (60) to seventy-five (75) per cent shall not be less than two inches in its least dimension. This layer shall be thoroughly compacted by rolling, and all defects in the surface shall be corrected before spreading on it any of the limestone screenings or wearing surface material. There shall then be cast upon this layer from the side of the roadway a sufficient quantity of clean limestone screenings to fill completely all interstices. This layer shall then be flooded with water and rolled until it is compact and solid and until it ceases to creep under the action of the roller, and until the screenings and water flush to the surface upon all parts of the roadway. The limestone screenings shall be clean and free from all clay, dirt, or other foreign matter, and of such size and quality as shall be acceptable to the Engineers. No sprinkling wagon having

tires less than six (6) inches in width shall be used to flush or water this layer.

Upon the second course, prepared in the manner above described, there shall be spread a layer of broken limestone, which, when thoroughly compacted by rolling, shall be two (2) inches in depth. The stone in this layer shall be of the quality previously described for the other layers, and shall be broken so that the greatest dimensions shall not exceed two and one-half (2½) inches and so that its least dimension shall not be less than one (1) inch. This layer shall be thoroughly compacted, without the use of any water, by rolling to the satisfaction of the Engineers. Should any unevennesses or depressions appear, they shall be filled with small-size broken stone and re-rolled until a firm, thoroughly compact, even surface is obtained that is true to the established finished-surface cross-section of the pavement.

Upon the above wearing surface an asphaltic cement of the quality specified previously for asphalt pavements, or of quality in every particular acceptable to the Engineers, shall be evenly spread with suitable apparatus, so as completely to coat all the stone and penetrate to the bottom of the wearing surface. Not less than two (2) gallons of asphalt to the square yard shall be used; and its temperature at the time of application must be between 300° and 350° Fahr. It shall be applied only when the stone is thoroughly dry. Immediately after the application of the asphaltic cement this layer shall be covered with a sufficient quantity of clean limestone screenings to fill completely all the interstices, and then the surface shall be thoroughly rolled to the satisfaction of the Engineers, until it is compact and solid, until the material ceases to creep under the action of the roller, and until the surface is smooth and true to grade. The quality of the limestone screenings shall be as previously specified for the other layers. The screenings shall be cast on the surface from the sides of the roadway. The surface of this wearing layer shall then be swept clean of all dust, dirt, or loose particles of macadam, and shall then receive a second application of the asphalt cement above specified. This coating shall completely cover all the stone; but care must be taken that no excess is applied. Not less than one-third (⅓) nor more than one-half (½) gallon of asphaltic cement per square yard shall be used for this course. Immediately after the application of this coating, another thin layer of screenings, as above specified, shall be applied to the surface of the road, and all shall then be thoroughly rerolled to the satisfaction of the Engineers.

I. 147. *Pavement Guarantee*

The Contractor will be required to give a guarantee, satisfactory to the Purchaser and substantiated by a surety company bond, to maintain the .... pavement for a period of .... (......) years from the date of its acceptance, correcting during that time, at his own ex-

pense, immediately upon the direction of the Purchaser, any defects that may occur. If at the date named the pavement is in proper condition, the Purchaser will accept it and release the sureties of the guarantee; or, if it is not in proper condition, the Contractor shall make all such corrections as the Purchaser may deem necessary to place it in perfect condition before final acceptance and the consequent release of the sureties.

P. 148. *Filling of Column Feet*

All boxed spaces at column feet of trestles, after being thoroughly painted and after the paint has dried, are to be filled with Portland cement grouting, mixed in the proportion of one (1) part of cement to two (2) parts of sand. If the Engineers so permit, two parts of fine broken stone or gravel may be mixed with the grouting, when the spaces to be filled are large.

P. 149. *Timber Construction in General*

The framing of all timber is to be done well and carefully by skilled carpenters, with neat joining and tight fitting throughout; and all timber work must be done in the most substantial and thorough manner practicable. Ample numbers of fastenings, as called for on the drawings, or as may be required by the Engineers, are to be used so as properly to connect all parts.

All timber bolts are to be of soft steel and are to have square or hexagonal heads and nuts and U. S. standard threads.

Wherever timber comes in contact with other timber or with the steel work it shall be thoroughly coated with hot asphaltum, and all holes which are bored in the timber are to be effectively saturated therewith. All bolts and washers which are to be placed in direct contact with the timber are to be warmed, then dipped in hot asphaltum.

P. 150. *Machinery and Shelter Houses of Timber Construction*

All materials used in the construction of the machinery houses and shelter houses shall be of the best quality. All lumber shall be first-class, seasoned material, conforming to the preceding general specifications for timber, except that the rough floors and the first sheathing may be of second quality material. All mill-work shall be of best quality, neatly joined and finished. The windows shall be of double-strength glass, all provided with sash weights and proper catches. The doors shall be of first-class mitered construction one and three-quarters ($1\frac{3}{4}$) inches thick, and shall be provided with satisfactory hinges and locks.

Houses shall be built on nailing strips bolted to the steel work. Lower floors shall be not less than two and one-half ($2\frac{1}{2}$) inches thick of material sized to thickness, on which shall be laid tongued-and-grooved flooring two (2) inches thick and surfaced on one side. The studding shall be two (2) by six (6) inches, unless otherwise noted, sheathed on the outside

with one (1) inch plank sized to thickness, placed diagonally on the studding and covered with building paper and with approved German drop siding. The inside of studding and ceiling joists shall be covered with three-quarter inch tongued-and-grooved ceiling. Adequate bridging and bracing shall be used as may be directed. Galvanized iron gutters and down spouts shall be provided to take all water from roofs and carry it below the roadways. The rafters shall be sheathed with one (1) inch dressed plank and covered with first class standing-seam tin roofing, to the satisfaction of the Engineers. One coat of approved paint shall be applied to the underside of the tin before laying, and the finished roof shall be painted with two coats of approved paint. Ridges shall be finished with galvanized iron ridge rolls, No. 18 gauge. There shall be provided an approved terra cotta flue and a chimney properly placed and supported; and a stove and piping shall be furnished and set up.

All enclosed or covered structural steel in houses shall receive the full specified painting before the houses are built. All houses shall be painted within and without with a coat of filler and two coats of first-class house paint of colors to be selected by the Engineers.

P. 151. *Machinery Houses and Shelter Houses of Fireproof Construction*

The machinery houses and shelter houses are to be of truly fireproof construction, consisting of steel frames, **reinforced-concrete or metal** floors, and approved metal lath and plaster walls and roof. The steel used therein will be paid for at the same price as the other carbon steel **of the river spans,** and the floors, walls, roofs, windows, and doors will be paid for at **the schedule rates (or by the lump sum)** named therefor in the Contractor's tender. The windows and doors are to be built in the best practicable manner according to the detailed plans; and the Contractor will be expected to furnish at his own expense all necessary materials and fittings of best quality and to the satisfaction of the Engineers. The roof shall be covered with tarred felt of the best quality, put on in the usual manner and to the satisfaction of the Engineers. There shall be provided an approved terra cotta flue and a chimney properly placed and supported; and a stove and piping shall be furnished and set up.

P. 152. *Permanent Stairways, Runways, Platforms, Etc.*

The Contractor shall furnish all the materials for and shall build complete all permanent stairways, runways, and platforms, painting all woodwork with filler and two coats of paint, all in accordance with the plans furnished and with the instructions given by the Engineers.

P. 153. *Smoke Protectors*

As shown on the drawings, the smoke protectors shall be constructed with metal lath and Portland cement mortar, mixed in the proportion of one (1) part of cement to two (2) parts of sand.

P. 154. *Laying of Rails*

The rails, together with all splices and all special work of every character, are to be laid to exact position and alignment and to correct gauge. They are to be placed with proper allowance for temperature at time of laying, as may be directed by the Engineers. The angle splice bars shall then be put on and all holes filled with well tightened bolts. The spiking is to be thoroughly and carefully done so as to injure the ties as little as possible. Two (2) spikes in every tie for each rail are to be used. They shall be five and one-half (5½) inches long and nine-sixteenths (9/16) of an inch square. The joints in each pair of rails shall be placed opposite.

V. 155. *Bonding of Rails*

This clause should specify the type of rail-bonds to be used and method of placing them. The cross-bonds should likewise be specified, as well as the provision to be made for maintaining the track circuit where a movable span is encountered.

EXAMPLE

The rails are to be bonded by the use of two (2) compressed terminal bonds, similar to Bond No. 7193 of the Ohio Brass Company, with seven-eighths (7/8) inch terminals and 4-0 cable ten (10) inches long, placed under the angle bars at each joint of each rail. The bonds are to be properly compressed into freshly drilled holes in the rail webs. Cross bonds of 4-0 cable with similar terminals are to be placed so as to connect the rails of each track not more than five hundred (500) feet apart. Bonds of similar size are to be placed around all special work, properly bonding the rails in a workmanlike manner to the satisfaction of the Engineers. All bonds are to be furnished and placed by the Contractor **for Erection.**

V. 156. *Railway Deck*

This clause should state who must furnish the materials for the deck and who is to place them.

EXAMPLE

The Contractor shall furnish and put in place, to the satisfaction of the Engineers, all the materials required for the railway deck.

V. 157. *Conduits and Gas Pipes for Lighting Systems*

Reference should be made to the drawings, which should show the layout for the conduits and gas pipes for the lighting systems as well as the points between which the conduits and gas pipes are to be furnished and placed. The sources of supply should be noted. The size and style of each conduit should be specified, and all details for making the conduits

waterproof and for providing easy drawing of the wires for the electric system should be given. The location of junction and switch boxes should be specified.

EXAMPLE

Loricated pipe conduit of one inch internal diameter shall begin at each light bracket and extend down the post to a control box provided in the base. From each of these boxes a conduit is to extend under the sidewalks to similar conduits running the full length of the bridge. Beyond the superstructure these conduits are to be attached to the retaining walls below the sidewalks. All connections are to be made so that wires connecting all light brackets can later be easily drawn into the conduits. Junction boxes shall be provided, one being placed at the top of each post. All joints in the pipe and joints between pipes and boxes shall be made watertight. Boxes in bases of posts are to have neat, cast-iron, hinged doors provided with locks.

Gas piping is to be provided and located as described for the conduits. Each pipe is to project upward to the top of the light post and be there supplied with a cut-off valve. All gas pipe is to be of single strength $\frac{3}{4}$ inch internal diameter, free from all flaws, and joined and fitted up in such a manner that no leakage of gas can occur. Each exposed end of pipe shall be covered with a cap.

V. 158. *Lamp-posts*

This clause should specify the material from which the lamp-posts are to be made; for instance, cast iron, bronze, or concrete, also the requirements as to fittings, connections, finish, and workmanship in general. The drawings should be referred to for details and dimensions, unless a post of standard make is to be employed, in which case this fact should be stated.

EXAMPLE

All lamp-posts shall be of cast iron of best quality. They shall be smooth and neat in finish and of the dimensions called for on the drawings. They shall be firmly bolted to the hand rail posts (unless they themselves act in that capacity), and a lead gasket shall be placed beneath them to ensure perpendicularity and to keep the iron from staining the concrete.

V. 159. *Carrying of Water-Pipes*

This clause should refer to the drawings for the location of the water-pipes and should specify the size, kind, and number of lines of pipe to be employed. The points between which the pipes are to be furnished and placed by the Contractor should be given, as well as the sources of supply. Provision for expansion and contraction under temperature

changes and against leaking should be noted; and for cold climates, where the pipes are liable to freezing, the method of protecting them should be stated.

EXAMPLE

As shown on the drawings, the spans are arranged to carry water-pipes over the structure. These pipes are of riveted steel. They are to be so connected as not to permit of leaking under any conditions, and they are to be protected against freezing, as indicated on the plans. Proper provision is to be made for their expansion and contraction under changes of temperature.

V. 160. *Pipe Line for Fire Protection*

There shall be given here a general description of the entire system, indicating the source of supply, the point of connection thereto, the length, size, and character of the pipe leading to the bridge, and the character of the pipe on the bridge, as well as the method of carrying it and attaching it to the structure.

As an example the following is quoted from an old specification:

DESCRIPTION

The source of supply will be the Leavenworth Water Works, a four (4) inch main of which passes through the yard of the engine house in the Military Reservation. This main is to be cut for the insertion of a Tee, from which will start a new four (4) inch line running eastward in a straight line some four hundred and seventy (470) feet till it reaches the brow of a hill, where it will turn and pass in another straight line diagonally down the slope to the western approach of the bridge, where a meter is to be located. The total length of four (4) inch pipe will be about seven hundred and eighty (780) feet. There will be one horizontal and two vertical curves in the whole length of four (4) inch pipe line. These curves will be made as easy as circumstances will permit.

After leaving the meter the diameter of the pipe will be reduced to two (2) inches. It will pass from the western approach onto the bridge, resting upon the guard rail; being blocked up therefrom so as to rise at the rate of one (1) foot in five hundred (500) to the middle of the main span, after which it will descend at the same rate till the east end of the eastern span is reached. It will then dip so as to pass under the wagon-way to the railway trestle, after reaching which it will rise suddenly to the upper surface of the ties, upon which it will rest outside of the guard timber and close to same, extending to within fifty (50) feet of the end of the trestle. The total length of two (2) inch pipe will be about twenty-six hundred and fifty (2650) feet.

SPECIFICATIONS FOR PIPE LINE

It is the intent and purpose of the following specifications to include every detail necessary to make the pipe-work and other apparatus complete; and should anything be omitted in these specifications which is necessary for the successful operation of the line, the same shall be supplied by the Contractor without extra charge.

UNDERGROUND PIPE

The......(....) inch pipes shall be of cast iron capable of withstanding a hydraulic pressure of......(....) pounds per square inch without rupture. They shall be of

a uniform length of not less than......(....) feet, and shall have good, strong, grooved bells, with seats at least............(....) inches in depth. All pipes shall be of uniform thickness, free from lumps or fins on the inside, and they shall have a uniform circular interior surface. The weight of a...........(....) inch pipe shall be........ (....) pounds per lineal foot, no variation from this weight exceeding five (5) per cent being allowed. All pipe shall be made of select grades of pig iron, which in broken sections of pipe shall show a sharp, gray fracture. The use of scrap in making the pipe will not be permitted. The Contractor shall be required to furnish a written guarantee of the makers of the cast iron pipe and special castings to the effect that the said pipe and specials have been subjected to an hydraulic pressure of.......... (....) pounds per square inch and have, at the same time, withstood a careful hammer test made with a heavy sounding hammer. Any lengths of pipe which show damage in handling or shipping shall be rejected. When, in the prosecution of the work, it becomes necessary to cut pipe, the ends of the pipe so cut shall be chiseled off smooth, and with the plane of the face at right angles with the axis of the pipe.

Laying Pipes in Trenches

All pipe must be fitted on the surface of the ground to insure proper jointing, and when laid in the trench shall be true to line and grade. A pit under each joint shall be excavated of sufficient depth and width to admit of thorough caulking of the joints, which must be done with proper tools. Every joint must be packed with oakum and lead, the lead joint to be not less than two (2) inches in depth; and, when caulked, it shall be water tight. In laying, the axes of the adjoining sections shall be in the same straight line; and the pipe, when laid, shall rest upon an oval bed, excavated in the trench for its reception.

Special Castings for Pipes

Special castings shall be of best quality of gray iron, the use of scrap not being permitted. They shall have all turns or corners moulded off to easy curvature, and shall be smooth on inner surface, with clear openings not less than the diameter of the connecting pipe. The weight of the......................................Tee shall not be less than............(....) pounds.

Gate Valves

There shall be two gate valves in the...........(....) inch pipe line, one located a few feet from the initial point, and the other a few feet from the meter. They shall be iron-bodied, of the double gate pattern, of the sliding type, and of neat workmanship and strongly built; and they shall be provided with composition stems and bell ends. All faces and seats shall be of non-corrosive metal. Both valves shall be cased up to the surface of the ground with............(....) inch iron casing, and shall be capped with adjustable bonnet or cover having a movable lid. Three (3) valve keys shall be furnished for each valve.

Meter

The meter to be used shall be a............(....) inch Standard Crown Meter, set in a thorough manner inside of a circular pit well lined with a concrete wall at least ....(....) inches thick. The top of the pit is to be provided with a cast iron cover-plate and frame. The internal diameter of the pit is to be............(....) feet, and that of the opening at the surface of the ground............(....) feet.

Trenches

The trenches are to be dug as narrow as practicable, and in no case less than four and one-half (4½) feet deep. Should rock be encountered in the trenches (which is

improbable), it must be excavated to a depth of six (6) inches below the bottom of the pipe, the space thus formed being filled with earth. Back filling on top of pipe shall be earth, free from stones to a depth of eighteen inches (18″) from the top of pipe. When the pipe is laid, the Contractor shall properly fill the trenches with layers of excavated material, provided it be suitable for the purpose, not over one (1) foot in thickness, and shall ram the same with suitable iron rammers.

Drainage

Proper valves shall be provided so as thoroughly to drain the meter and the pipe line on the structure.

Pipe on Structure

The pipe on the structure shall be of steel, and shall have an internal diameter of ....(....) inches. It shall be of standard strength and thickness, the lengths being connected by sleeve couplings with screw joints, which joints shall be properly filled with pure asphaltum.

Valves on Bridge Pipe

Once in about every one hundred (100) feet on the............(....) inch pipe there shall be placed, opening upward, a...........(....) inch, brass-body, Chapman or Lunkenheimer gate valve with a two (2) inch brass hose nipple, so as to permit the hose to be quickly and effectively attached; all to be securely and properly put in place.

Fastening of Bridge Pipe

The pipe on the structure shall be firmly attached thereto, and proper arrangements shall be made for expansion and contraction, providing for a maximum motion of one (1) inch in every one hundred (100) feet. This is to be accomplished by using ....(....) expansion joints, located as shown on the drawings. The expansion joints shall be of approved pattern and make, and shall be iron-bodied with brass sleeves.

Linen Hose and Boxes Therefor

There shall be provided............(....) pieces of two (2) inch standard linen hose of the best quality, each............(....) feet long, and furnished with hose coupling and three-quarter (¾) inch nozzle complete. For each hose there is to be provided and secured in place (the positions being shown on the drawings) a strong wooden box with a good lock. The locks on all the boxes must be alike, and.......... (....) keys must be furnished.

Painting the Pipe Line

All pipe work and fittings, whether under ground or exposed, shall be thoroughly coated on both outside and inside with pure asphaltum varnish of best quality.

Materials and Labor on Pipe Line

All materials used shall be of the best quality of their respective kinds; and all labor shall be performed in a thorough and workmanlike manner.

Test of Pipe Line

After the completion of the work, the entire pipe line shall be inspected by the Engineers, and shall be tested by turning the water on. The test shall not be considered complete until after the pipe line has been in use two (2) weeks. Any defect found before the expiration of such time shall be remedied by the Contractor without extra charge, to the complete satisfaction of the Engineers.

V. 161. *Waterproofing*

In this clause should be stated the parts of the structure to be waterproofed and the method to be employed for each particular part. A waterproofing mat is generally specified and its make-up and construction should be clearly indicated. A standard waterproofing material that has proved its effectiveness should be specified with the proper provision for adopting any other waterproofing material that meets the approval of the Engineers.

Example

Waterproofing under Ballast.

The surfaces of the slabs and of the faces of curbs up to the top of the ballast are to be waterproofed by the following method: On the clean, dry surface of the concrete there shall be applied with brushes a coating of Sarco concrete primer or any other primer satisfactory to the Engineers, which coating, as applied, shall be thin enough to penetrate the recesses of the concrete, forming an anchorage for subsequent waterproofing. After the priming coat has dried, there shall be applied with mops a heavy coating of Sarco No. 6 waterproofing pitch (or similar waterproofing pitch satisfactory to the Engineers) which has been heated to a temperature of 400° Fahrenheit; and, while this material is still hot, there shall be placed upon it a layer of eight (8) ounce, open-mesh burlap carefully put down, free from folds or pockets, and with edges lapped at least four (4) inches and sealed with waterproofing pitch. The surface of this burlap shall be heavily swabbed with the waterproofing pitch specified, and a second layer of eight (8) ounce, open-mesh burlap shall be laid in the same manner, making a two-ply burlap mat thoroughly saturated, cemented, and bonded together into the concrete with the waterproofing pitch. Another coating thereof shall be applied as before, and on this mat there shall be placed a layer of asphaltic felt, weighing not less than fourteen (14) pounds per hundred square feet, with edges lapped at least four (4) inches and sealed with waterproofing pitch. The surface of the felt shall then be swabbed with the said pitch and covered with a one-inch thickness of Sarco Mastic, or other asphaltic mastic satisfactory to the Engineers. This shall be carried up the curb walls to the top of the ballast so as to protect the waterproofing mat against punctures from the rock ballast. The surface of this mat shall be heavily swabbed with the pitch specified, and shall be given a sand finish while the material is still hot. Proper joints connecting the waterproofing to the curb and at the expansion joints shall be made as may be directed.

Waterproofing under Wood Block Pavement.

On the clean and dry surface of the concrete slabs and curbs there shall first be applied, with brushes, a coating of Sarco concrete primer, or other

concrete primer satisfactory to the Engineers, which coating as applied shall be thin enough to penetrate the recesses in the concrete, forming an anchorage for the waterproofing coating. After this priming coat has dried, there shall be applied with mops a heavy coating of Sarco No. 6 waterproofing pitch (or other waterproofing pitch satisfactory to the Engineers) which has been heated to a temperature of 400° Fahrenheit; and while this layer is still hot, there shall be placed on it a layer of eight (8) ounce, open-mesh burlap carefully put down, free from folds and pockets, and with the edges lapped at least four (4) inches and sealed with waterproofing pitch. The surface of this burlap shall be heavily swabbed with the said pitch; and while the material is still hot, there shall be placed on it one layer of asphaltic felt, weighing not less than fourteen (14) pounds per hundred square feet, with edges lapped at least four (4) inches and sealed with waterproofing pitch. The surface of this felt shall then be heavily swabbed with the said pitch and given a sand finish while the material is still hot. This surface shall be kept free from injury until the pavement is in place. Proper joints connecting the waterproofing to the curbs and at the expansion joints of the structure shall be made as may be directed.

P. 162. *Erection of Steel*

The Contractor **for Erection** shall furnish all falsework, staging, barges, and equipment, and shall erect, adjust, rivet, and paint all metal-work. Attention is called to the fact that, before shipment from the shop, all trusses and towers are to be assembled and the field holes reamed, and all field connections in the floor system are to be reamed while the members are assembled, or by using an accurate steel template. All trusses, spliced columns, and similar members are to be match-marked and must be erected in accordance with such marking. The **Erecting** Contractor shall furnish and supply without charge all necessary temporary bolts for erection.

All parts are to be carefully handled and accurately assembled. Excessive hammering which would injure or distort the material shall not be resorted to.

Truss spans shall be erected on blocking placed so as to give the trusses the proper camber, and the blocking shall be kept at correct elevation until all truss connections are completely riveted up.

Bearing surfaces shall be cleaned before being placed together; and rollers and sliding shoes shall be both cleaned and oiled. Riveted connections shall be accurately and securely fitted up before the rivets are driven. Holes which do not match shall be reamed. Drifting which would distort the metal or gouging shall not be permitted. Fitting-up bolts shall be placed in at least every third hole.

P. 163. *Correction of Errors of Connections* *

It is probable that there will be some misfits in the connections of the steel work, of the machinery, of the machinery to the steel work, and of the timber to the steel work; and the **Erecting** Contractor shall be required to make all necessary adjustments and corrections in all parts to assure their proper connection. A usual amount of drifting, drilling, and correcting bad connections, and of scraping, lining, and preparing bearings is expected, and is to be done by the **Erecting** Contractor without additional payment. Whenever, in the opinion of the Engineers, there is found to be an unusual and unreasonable amount of correction of shop errors, or correction of manufactured articles, the **Erecting** Contractor shall be paid for such as "Unclassified Work" under this contract; provided, however, that when the **Erecting** Contractor encounters cases wherein an extra payment seems properly due, he shall call the attention of the Engineers thereto, and if they decide that such is the case, they will give a written order, and the **Erecting** Contractor shall perform the work and shall present receipted detailed bills and vouchers for all expenses incurred, as provided under the "Unclassified Work" clause. No claims for extras due on such work will be considered at all, unless a definite written order is given therefor by the Engineers before the said extra work is started. If the Engineers decide in any such cases brought to their attention that extra payment is not proper, the **Erecting** Contractor shall proceed to perform the work, but no extra payments will be made and no claims therefor will be considered. All extra payments allowed the **Erecting** Contractor for correcting shop errors shall be paid by the Purchaser and deducted from the compensation of the Contractor for the manufacture and delivery of the metal work and machinery.

P. 164. *Falsework for Carrying Trains*

The Contractor **for Erection** must provide falsework of ample strength and rigidity to carry safely the trains of the Purchaser; and the plans for it must receive the written approval of the Engineers before the materials for the said falsework are ordered.

P. 165. *Erection Barges*

Whenever any spans are to be floated into position, the Contractor is to prepare complete plans for the necessary barges and falsework; and these must be submitted to the Engineers and receive their approval before being used, as must also the general scheme of doing such flotation.

P. 166. *Cement*

All cement used on the work must be Portland cement of the very best quality obtainable, equal in every respect to the best brands of

* This clause is to be omitted when the Manufacturer does the erection.

American and European manufacture, and delivered at site in strong, close barrels, well lined with paper, so as to be reasonably secure from air and moisture, unless the Engineers give written permission to deliver it in bags. Each barrel shall be labeled with the name of the brand, place made, and name of manufacturer.

The cement shall be ground so fine that at least ninety-two (92) per cent in weight will pass a standard sieve of ten thousand (10,000) meshes to the square inch, and so that at least seventy-five (75) per cent will pass a standard sieve of forty thousand (40,000) meshes per square inch.

When moulded neat into briquettes and exposed three (3) hours, or until set, in air and the remainder of twenty-four (24) hours in moist air, it shall develop a tensile strength of at least one hundred and seventy-five (175) pounds per square inch. When moulded neat into briquettes, after exposure of one (1) day in air and six (6) days in water, it shall develop a tensile strength of at least five hundred (500) pounds per square inch; and after exposure of one (1) day in air and twenty-seven (27) days in water, it shall develop a tensile strength of at least six hundred (600) pounds per square inch. It shall be an eminently slow-setting cement, must develop its strength gradually, and must show no drop therein.

When moulded neat into pats with thin edges and either left on glass or not to set in either air or water, the said edges must show no signs of checking. The cement shall withstand properly the standard steam test of the American Society for Testing Materials, which consists in exposing the pats in any convenient way in an atmosphere of steam, above boiling water, in a loosely closed vessel for five (5) hours, and requiring that they shall remain firm and hard, and shall show no sign of distortion, checking, cracking, or disintegrating.

The cement, when mixed neat with about twenty-two (22) per cent of water to form a stiff paste, shall after thirty (30) minutes be indented perceptibly by the end of a wire one-twelfth ($1/12$) of an inch in diameter loaded to weigh one-quarter ($1/4$) of a pound. The hard set, determined similarly with a wire one-twenty-fourth ($1/24$) of an inch in diameter and loaded so as to weigh one (1) pound, shall not occur in less than three (3) hours, unless the Engineers permit the use of quick-setting cement for some special purpose, in which case this time limit may be reduced as low as one (1) hour, but no lower.

Briquettes mixed in proportion, by weight, of one (1) part of cement to three (3) parts of sand, and kept one (1) day in air and the remaining time in water, shall show a tensile strength of at least two hundred (200) pounds per square inch after seven (7) days, and at least two hundred and seventy-five (275) pounds per square inch after twenty-eight (28) days.

In any case the cement adopted must first be approved by the Engineers.

The Contractor shall provide a suitable building for storing the cement, in which the same must be placed before being tested. The Engineers shall be notified of the receipt of cement for testing at least thirty (30) days

before it is required for use, and the Inspector may take a sample from each package for the said testing. The Engineers will insist that no cement shall be used that has not been subjected to their twenty-eight (28) day test, and the Contractor must understand at the outset that this requirement will be insisted upon, even if the progress of the work be delayed thereby.

Any cement that has caked so as, in the opinion of the Engineers, to be injured shall be rejected; and it shall be removed by the Contractor from the neighborhood of the site in order to avoid all possibility of its being employed on the work.

P. 167. *Sand*

Sand shall be defined as particles of hard, clean stone which will pass a sieve having holes one-quarter (¼) inch square, and not less than fifty (50) per cent of which shall be retained upon a sieve having holes twenty-two thousandths (0.022) of an inch square, or what is commonly called a No. 30 sieve. It must be free from clay, silt, chips, and all other impurities, and must be reasonably sharp. In all cases the Engineers shall decide as to whether any sand offered by the Contractor shall be used on the work. If it be not satisfactorily clean, sand may be used if it is first washed or otherwise cleaned to satisfactory condition.

P. 168. *Broken Stone or Gravel*

Where not otherwise specified, either broken stone or clean, hard gravel of qualities satisfactory to the Engineers may be used in making concrete. The broken stone shall consist of pieces of hard and durable rock, such as trap, limestone, granite, or conglomerate, which shall be free from dust, clay, loam, or other material in such amounts as would, in the opinion of the Engineers, impair the strength of the concrete. The stone shall be crusher-run up to the sizes specified, with all material that will pass a one-quarter (¼) inch screen removed.

The gravel shall be composed of clean, hard pebbles screened to the specified sizes (crushed where necessary), free from clay, loam, or other material in such amounts that would, in the opinion of the Engineers, impair the concrete. Material that will pass a one-quarter (¼) inch screen must be taken out.

If they be not satisfactorily clean, materials may be used, provided they are washed or otherwise cleansed to satisfactory condition. Stone or gravel shall be stored on board platforms, and must not be shoveled up from the ground.

P. 169. *Concrete*

Broken stone shall, preferably, be employed in making concrete, but wherever gravel of a character satisfactory to the Engineers is available,

it may be used either with or without broken stone, the determination of volume of voids being left to the Engineers. In all cases the volume of cement used shall be at least ten (10) per cent greater than the volume of the voids in the mixture of sand, gravel, and stone as determined by actual experiments and not by theoretical calculations; and in no case shall there be used less than the following weights of cement per cubic yard of finished concrete:

For aggregates in which all the materials are measured separately before mixing, four hundred and twenty (420) pounds.

For aggregates in which a natural mixture of sand and gravel is taken from the pit and modified by the addition of other material, four hundred and sixty (460) pounds.

For aggregates composed of a natural mixture of sand and gravel used without modification, five hundred (500) pounds.

In large masses of concrete one-man stones may be employed, provided that they first be cleaned and wetted thoroughly, and provided that they be not placed any nearer than six (6) inches to each other or to the exterior of the construction.

As previously specified, suitable forms of smoothly dressed timber must be provided to give the concrete constructions the dimensions and finish shown on the drawings, all exposed corners being rounded off so as to produce a neat finish and in order to prevent chipping.

The proportions for ordinary broken-stone concrete shall be as follows:

1 part of Portland cement,
3 parts of clean, coarse, sharp sand,
5 parts of broken stone, to pass a two and a half (2½) inch iron ring.

Those for reinforced concrete shall be as follows:

1 part of Portland cement,
2 parts of clean, coarse, sharp sand,
4 parts of broken stone, to pass a one and one-quarter (1¼) inch iron ring.

Those for special concrete shall be as follows:

1 part of Portland cement,
2 parts of clean, coarse, sharp sand,
3 parts of broken stone, to pass a three-quarter (¾) inch iron ring.

The latter proportions are to be used also for all concrete that is to be placed under water before setting.

The amounts of all ingredients are to be determined by volume, and the measurements are to be made loose. One barrel of cement, weighing 380 pounds net, shall be considered to measure four cubic feet, or one standard size bag of cement shall be considered to measure one cubic foot. The sand and the broken stone or gravel shall be accurately measured by delivering to wheelbarrows or to the mixers through boxes

or compartments of known volume. The method of measuring the ingredients of the concrete and the quantity of water used must be subject to the approval of the Engineers.

All surfaces of concrete constructions that are to be exposed to view are to be covered with an inch and a half (1½) shell of Portland cement mortar mixed in the proportion of one (1) part of cement to two (2) parts of sand and carried up simultaneously with the concrete.

The *modus operandi* of the construction of this shell shall be as follows, unless the Engineers give the Contractor written permission to employ some other method:

Steel plates one-quarter (¼) inch thick by twelve (12) inches wide and from four (4) to five (5) feet long are to be placed all around the construction at a distance of one and a half (1½) inches from the forms, and are to be blocked out from the latter every twelve (12) inches by small pieces of wood, the ends of the plates lapping slightly. Then the concrete is to be put inside the box thus formed to a depth not exceeding ten (10) inches and tamped thoroughly. Meanwhile the mortar is to be placed between the steel plates and the wooden form to a depth of about eleven (11) inches and tamped down, the wooden plugs being withdrawn gradually as the tamping proceeds. As soon as the exterior space is thus filled and before either the concrete or the mortar has had time to set, the steel plates are to be withdrawn by means of hooks inserted in holes placed near the upper edge for this purpose; then the mortar is to be rammed again so as to fill the voids left by withdrawing the plates.

If any bidder deem that this method of ensuring a smooth exterior is materially more expensive than that of omitting the outside mortar and the plates and, instead, of spading back carefully all the stones from the face, as is often done, he may state in his tender the difference in the price per cubic yard of concrete that the adoption of the latter method would cause; and due consideration will be given to this difference in awarding the contract. Such a bidder, however, is hereby warned that in no case will a rough exterior be accepted; nor will smoothing off with mortar afterward be permitted without special written permission from the Engineers.

All concrete is to be mixed by machinery, unless the Engineers permit otherwise. Batch mixers will be given preference over continuous mixers; and the latter will not be allowed on the work without special written permission from the Engineers. Whatever type or types of mixer be employed, the same must first receive the approval of the Engineers, and the method of supplying the materials to the machine must also meet with their approval, as must also the quantity and quality of the water used, which must be free from oil, acids, strong alkalies, and vegetable matter. The machine shall be operated long enough after the last ingredient is deposited in it to mix and to incorporate thoroughly all ingredients to the satisfaction of the Engineers.

When concrete is mixed by hand, the mixture of sand and broken stone or gravel is first to be spread in a thin layer on a timber platform, then the cement is to be spread on top thereof, then the mass is to be mixed thoroughly while dry, after which the proper quantity of clean water is to be added gradually while the said mass is being turned over and mixed until the mortar thus formed covers the pieces of broken stone or gravel entirely, and until the concrete attains the proper consistency. If broken stone be used with gravel, it is to be wet thoroughly, then added to the wet mass during the mixing.

Concrete shall be made with at least so much water that comparatively light tamping will be required to cause the mortar to fill all the interstices of the stone; but the use of an excess of water is to be avoided. Immediately after the mixing is finished, the concrete shall be conveyed to place in such a manner that there shall be no separation of the different ingredients. It shall be rammed, tamped, or tramped with rubber boots thoroughly in layers not exceeding twelve (12) inches in thickness, or otherwise agitated by suitable tools so as to produce a thoroughly compact concrete of maximum density; and so that all interstices are filled, and so that the concrete will present a smooth, finished, unbroken mortar surface without exposed stones, when the forms are removed; whether the exterior of the mass be mortar alone or concrete. Should any concrete receive its initial set before being placed, it shall be rejected and removed immediately from the site of the work. Concrete in long columns, or in deep, narrow walls shall be placed through a trémie.

Should, during construction, any surfaces of concrete be allowed to harden or dry before the other concrete is placed thereon, they shall be swept perfectly clean with brooms, then wetted thoroughly with clean water and covered with a thin layer of one-to-one grout, so as to make a perfect contact between the old and the new work, and thus ensure that the entire mass of concrete will be truly monolithic. The forming of such dry surfaces, however, shall always be prevented, if practicable; and in all cases the placing of concrete shall be stopped only at such points as the Engineers may direct.

If it prove necessary to place concrete during freezing weather, the Contractor shall take all such precautions as the Engineers may direct to prevent it from being frozen.

All concrete shall be kept damp until thoroughly set by drenching it or the forms containing it twice a day.

If, notwithstanding extreme care in the construction of forms and the placing and ramming of concrete, any imperfections be found on the exposed surfaces when the forms are removed, the said imperfections shall either be rubbed smooth or be floated with a mortar composed of one (1) part of Portland cement and two (2) parts of sand, the choice of the method to adopt being left to the Engineers.

All concrete deposited under water shall, preferably, be placed by

means of a water-tight trémie, but buckets which open beneath and which are tripped by contact with the bottom may be used, if the Engineers approve. Buckets tripped by a line operated from above shall not be employed.

P. 170. *Continuity of Operation in Placing Concrete*

Whenever the Engineers shall so direct, the Contractor shall so conduct his work that the placing of concrete for any integral part of the structure shall be continuous and without any interruption whatsoever from start to finish. The Contractor shall not begin to place concrete for any integral portion of the construction until he shall have on the site of the work adequate materials, which have been inspected and accepted, to construct the said portion of the work without interruption.

P. 171. *Granitoid*

Wherever the plans call therefor, the tops of piers, pedestals, and abutments shall be finished off with granitoid of the following proportions:

One (1) part of Portland cement; two (2) parts of clean, coarse granite sand, or fine granite screenings; and three (3) parts of granite chips broken so small as to pass a one-half ($\frac{1}{2}$) inch iron ring. The top of this granitoid is to be brought to an exact level and finished with a floated surface. The thickness of the granitoid is to be as shown on the plans.

P. 172. *Wooden Piles and Pile Driving*

All piles are to be cut from live, straight, sound timber of a quality acceptable to the Engineers. They must be free from cracks, wind-shakes, and all serious defects; and they must be so straight that a right line joining the centres of ends of pile shall show that the said pile is at no point over one-third ($\frac{1}{3}$) of its diameter at such point out of straight line. They must show a gradual, even taper from end to end. The ends must be cut square; all bark must be taken off; and the branches and knots must be trimmed smooth, finishing the piles in a workmanlike manner. Unless otherwise specified, they must not be less than nine (9) inches in diameter at the top, and not less than twelve (12) inches nor more than sixteen (16) inches in diameter at the butt. They must be spaced accurately as per plans, and must be driven vertically or to correct batter and to the satisfaction of the Engineers, and, when required, they shall be cut off to exact level. All piling not conforming to these specifications will be rejected.

The Contractor shall provide a suitable and efficient pile-driver for driving the piles to the required depth without splitting them; and he must furnish, if the Engineers deem them necessary, rings and shoes for any or all piles.

Whenever the Engineers so require, the piling is to be driven by means of water-jets; and the apparatus used therefor must first be approved by the Engineers. Two jet-pipes per pile, one on each side thereof, must invariably be used, because a single jet causes the point of the pile to travel toward the side where the jet is attached. The Engineers will insist that at the outset of his operations the Contractor shall provide for an ample volume of flow and an ample pressure of water for driving the piles; and the Engineers' judgment in this matter shall govern.

P. 173. *Concrete Piles*

Concrete piles that are to be manufactured and then driven are to be properly reinforced, as shown on the plans, great care being taken to ensure that the reinforcing metal is placed and held firmly in the correct position. The piles are to be allowed to harden for as long a time as the Engineers deem requisite. Any piles cracked or otherwise seriously injured in handling or before driving shall be rejected. All reinforced concrete piles of this general type are to be driven by water-jets, as previously specified for wooden piles, the use of the hammer to aid in driving being mainly confined to static loading. If the top of any pile be injured by hammering, the Engineers will reject it, if they see fit, and will cause it to be withdrawn and removed from the site.

If the concrete piles are to be manufactured in place, the method of manufacture must receive the approval of the Engineers; and they shall be at liberty at any time to withdraw or dig out a pile so as to determine how satisfactorily the manufacturing has been done and the suitability of the method to the locality. If this test prove to be unfavorable to the method, the Engineers shall have the privilege of rejecting it and adopting some other.

P. 174. *Position of Piers, Pedestals, and Abutments*

All piers, pedestals, and abutments, when finished, must be in exact position and to exact elevation, and all anchor-bolts therein must be located with the greatest exactness in respect to both horizontal position and elevation. The Contractor must provide all guide piles, anchors, cables, frames, and forms that may be required to ensure this result.

In sinking caissons by either the pneumatic or the open-dredging process, in order that the pier-shafts may be in exact position, the neat work of the latter shall not be begun until the caisson has reached its final position, unless the Engineers give written permission to the contrary. The Contractor shall provide a sufficient height of cofferdam for each pier in order to secure this result without running any risk from overflow.

It must be distinctly understood by all concerned that the onus of getting all piers, pedestals, and abutments into correct position, both

horizontally and vertically, lies upon the Contractor and not upon the Engineers, and that if any error therein be found, the Contractor will have to make at his own expense all the changes necessary to correct the error, or else he must stand the entire expense involved in modifying the superstructure to suit the faulty location of the substructure.

P. 175. *Depths of Foundations*

All cribs, footings, and caissons are to be sunk to the depths shown on the Engineers' plans or to such other depths as the Engineers may deem necessary as the work progresses. The data furnished to bidders by the Engineers regarding depths of foundations or of bed-rock are to be considered as merely approximate; and bidders must assume the risk of having to go a greater or less depth without altering in any way their schedule of prices. If, however, the Engineers consider that the Contractor is really entitled to extra compensation on account of material variation from the data furnished, such extra compensation will be allowed, but the amount thereof shall be determined solely by the Engineers.

If, too, during the progress of the work the Engineers deem that further investigations concerning the elevations of bed-rock or quality of materials for foundations are necessary, the Contractor shall make under the direction of the Engineers, all the borings, tests of bearing capacity of soil, or other similar investigations which the said Engineers may consider to be requisite; and such work shall be treated as herein provided for "Unclassified Work."

P. 176. *Caissons Sunk by the Pneumatic Process*

The construction of all caissons and cribs shall be in accordance with the accompanying detail plans; and the Contractor's working drawings shall be made to conform thereto. The said working drawings must be approved by the Engineers before work on the caissons is started.

In case of all-steel caissons, the Contractor in making the working drawings shall adhere strictly to the Engineers' details; and in case of timber caissons the following directions must be observed:

First. All timbers are to be of the full length or width of the caisson whenever this is practicable.

Second. The cutting edges are to be shod with steel, unless specifically indicated to the contrary on the drawings.

Third. Drift-bolts are to be spaced not to exceed four (4) feet along each stick, and preferably about three (3) feet.

Fourth. All framing of timber is to be done in a substantial manner so that the crib and caisson will hold their shapes in case that it be found necessary to force the cutting edges through logs or masses of large boulders.

Fifth. Cribs and caissons are to be made water-tight by calking. Removable coffer-dams are to be used above the cribs in order that the

lower portions of the pier-shafts may be built in the dry; and the timbers for same must in all cases be removed before the work will be accepted. No direct payment will be allowed for these cofferdams, as their cost must be covered by the prices for concrete or masonry above water and for mass of cribs and caissons below water.

P. 177. *Caissons Sunk by Open Dredging*

The construction of these caissons, cribs, or shells shall be in accordance with the detail plans. The Contractor must prepare complete working drawings for all such caissons, cribs, or shells, and must submit the same to the Engineers for their approval before work thereon is started. If it be intended to pump the water out of the steel shells, they shall be made water-tight by calking the joints wherever the latter will not be sealed by the concrete; and this calking must be done to the satisfaction of the Engineers. In case of all-steel construction, the Contractor in making the working drawings shall adhere strictly to the Engineers' details; and in the case of timber construction the following directions must be observed:

First. All timbers are to be of the full length or width of the caisson whenever this is practicable.

Second. The cutting edges are to be shod with steel, unless specifically indicated to the contrary on the drawings.

Third. Drift-bolts are to be spaced not to exceed four (4) feet along each stick, and preferably about three (3) feet.

Fourth. If the Engineers deem them necessary, vertical pipes for injecting water so as to loosen the material near the cutting edges must be built into the timber and concrete as the construction proceeds. They are to be spaced not to exceed eight (8) feet centres, and are to lie close to the walls of the working chamber, being fastened rigidly thereto so as to resist dislodgment during sinking. To prevent their becoming clogged with earth or gravel during the sinking, their bottoms are to be fitted with tight wooden plugs; and when the pipes are needed for jetting purposes, the said plugs are to be driven out by using a smaller pipe for a ram.

Fifth. All framing of timber is to be done in a substantial manner, so that the crib and caisson will hold their shapes in case that it be found necessary to force the cutting edges through logs or between large boulders.

Sixth. Cribs and caissons are to be made water-tight by calking.

Removable cofferdams are to be used above the cribs so that the lower portions of the pier-shafts can be built in the dry; and the timbers for same must in all cases be removed before the work will be accepted. No direct payment will be allowed for these cofferdams, as their cost must be covered by the prices for concrete or masonry above water and for mass of cribs and caissons below water.

P. 178. *Cofferdam Work*

In all cofferdam excavation, the designing of the cofferdams will be left to the Contractor, who will be held responsible for the ultimate completion of the piers, pedestals, or abutments for which the said cofferdams are used; but the designs must be approved by the Engineers before any of the work of construction is started. The cofferdams shall be so designed and built as to permit of all the water being pumped therefrom, in order that the footings may be laid in the dry, provided that this be practicable. If, however, in the opinion of the Engineers, it be impracticable, the construction shall be carried out by placing the concrete under water by means of a trémie or other special apparatus for the purpose that is approved by the Engineers. In this case specially rich concrete of small broken stone, as herein specified, shall be used. No direct payment will be made for cofferdam materials, as the cost thereof must be covered by the prices for excavation or materials in place. All timber and other cofferdam materials above the level of the ground or above that of extreme low water is to be removed by the Contractor from around the piers, pedestals, and abutments before his work will be considered completed; and no direct payment will be allowed for such removal, its cost being covered by the prices for the excavation or for the materials in place.

P. 179. *Maintaining Correct Form of Steel Shells*

In riveting up and sinking steel shells the greatest care is to be taken to keep them true to form; and no off-setting or divergence at joints will be permitted, unless so shown on the drawings. In many cases it will be necessary to bolt timbers to the shell temporarily, consequently the Contractor will be required to provide the necessary angle lugs therefor. As the onus of getting the shell down in proper shape is on the Contractor, the designing of the stiffening is to be done by him; notwithstanding which he must submit the design to the Engineers for approval before work is begun. All stiffening timbers must be removed before the concrete is put in, and, wherever necessary, before the piles are driven.

P. 180. *Excavation*

For caissons sunk by the open-dredging or the pneumatic process, no allowance will be made for the cost of excavation, this expense being covered by the price for mass of crib and caisson, or other materials, in place; nor where cofferdams are employed or where pits are dug will the excavation be paid for, unless this be specifically so stated in the contract. In computing the volume of excavation to be paid for in any pit, the sides of the latter are to be assumed as vertical, and no area will be allowed greater than that of a rectangle having each side longer by two (2) feet

than the corresponding side of the base of footing of the pier, pedestal, or abutment. No payment will be made for timber used in shoring, siding, or sheeting, nor for pumping nor bailing, as the cost thereof must be covered by the prices allowed for excavation or for materials in place.

Excavations for all constructions are to be carried to such depths as the Engineers may direct; and if, in their opinion, the foundation require any special preparation, it shall be given to it by the Contractor, the work involved thereby being paid for as "Unclassified Work," if the Engineers deem that it should be so considered.

Where bedrock is reached, the caisson, base, or footing, as the case may be, whenever practicable by ordinary methods, must be sunk into it one foot or as much more as the Engineers may consider necessary to obtain an even and proper bearing and a satisfactory anchorage against slipping. If the Engineers deem that the cost of such sinking into bedrock is unusual or excessive, they will allow additional payment therefor, as per the "Unclassified Work" clause of these specifications; but the amount of such payment shall be determined solely by the Engineers.

P. 181. *Encountering Obstacles*

Bidders must assume the risk of encountering logs, boulders, and other obstacles under the surface of the ground at the sites of the piers and abutments, and the Contractor must provide himself with all the necessary tackle and apparatus for handling the same. There will be no extra price allowed because of the difficulty experienced in sinking or driving through or in removing the said obstacles.

P. 182. *Pile Foundations*

The bases of piers, pedestals, and abutments which are to rest on piles shall be constructed by excavating within and sinking cribs, as indicated on the plans, to the required depth (preferably before the piles have been driven, but afterward, if the Engineers approve of that procedure). If the piles are driven after the crib is sunk, the earth which they force up into the crib shall invariably be removed; then the concrete shall be deposited in the dry, if practicable; otherwise through a trémie or by means of a single-line bottom-dumping bucket till the crib is filled uniformly to an elevation about two (2) feet below that at which the piles are to be cut off. If it be deposited in the dry, the concrete shall be thoroughly tamped or tramped with rubber boots in layers about one (1) foot deep. If it be deposited under water, it shall be mixed in the proportions hereinbefore specified for concrete deposited under water, and the crib shall be filled evenly over its area. As soon as the concrete has hardened adequately, the water shall be pumped out, the pile heads cut squarely off at the required elevations, and the remainder of the base built in the dry. The cribs shall be adequately caulked and braced to

withstand the exterior water pressure when they are pumped out, and they shall be surmounted by cofferdams of adequate strength and height to protect the construction from the highest water, and to carry whatever weight is required to sink the crib. The construction of the cribs shall be in accordance with the Engineers' general detail plans, but the designing of the temporary stiffening shall be left to the Contractor. The Contractor must prepare complete working drawings for all cribs, and must submit the same to the Engineers for their approval before work thereon is started. All timbers are to be of the full length or width of the crib whenever this is practicable. Drift-bolts seven-eighths (⅞) of an inch in diameter by twenty-two (22) inches long are to be spaced not to exceed four (4) feet along each stick, and preferably about three (3) feet. All framing of the timber is to be done in a substantial manner so that the crib will hold its shape in case that it be found necessary to force the cutting edges through obstacles.

Should the Contractor so elect, he will be permitted to use sheet piles or cofferdam construction, but in such cases the concrete bases of the piers must be made of the same gross size as that shown on the drawings for the outside of the crib timbers.

The length and penetration of the foundation piles are to be determined by the Engineers. They will be paid for by the lineal foot of pile projecting below the crib-base; and a proper allowance will be made for the actual cost of the cut-off ends.

P. 183. *Brick Piers*

The bricks must be sound, hard-burned, vitrified, and acceptable to the Engineers. They must be wetted thoroughly before being laid, and the mortar therefor shall be the same as that specified for stone masonry, the joints being not less than one-quarter (¼) of an inch nor more than one-half (½) of an inch thick, and the average not exceeding three-eighths (⅜) of an inch. All brickwork shall be laid in Flemish bond, *i. e.*, alternate headers and stretchers with consecutive courses breaking joint. All joints shall be finished properly as the work progresses. The piers may be built of solid brickwork, or may consist of a brick shell backed with concrete. None but expert bricklayers shall be employed to lay the brick; and all details of the work shall accord with the most approved practice and must be to the satisfaction of the engineers.

P. 184. *Masonry in General*

All masonry piers, pedestals, and abutments shall be built of either first-class or second-class masonry, no third-class masonry or round-stone rubble masonry being permitted. The shells alone of first-class construction shall be of masonry, the backing being invariably of Portland cement concrete as hereinbefore specified for interior work. The stone employed

shall be sound and durable and free from all drys, shakes, or flaws of any kind whatever. It must be of such a character that, in the opinion of the engineers, it will withstand properly the action of the weather and the grinding effect of ice and drift. No stone of any inferior quality will be accepted or even be permitted to be delivered on the ground. The masonry shells shall be filled solid with the concrete backing, so that each pier, pedestal, and abutment shall be a true monolith.

P. 185. *First-Class Masonry*

All first-class masonry shall be regular coursed ashlar of the best description, and must be laid in Portland cement mortar of the proportions of cement and sand hereinafter specified. All stones must be so shaped that the bearing beds shall be parallel to the natural beds, and they must be prepared by dressing and hammering before they are brought on the walls, as tooling and hammering will not be allowed after the stones are in place. They are to be laid to a firm bearing on their natural beds in a full bed of mortar, without the use of chips, pinners, or levers. No shelving projections will be allowed to extend beyond the under bed on either side. The stone and work are to be kept free from all dirt that would interfere with the adhesion of the mortar. The stones must be sprinkled with water before being placed in position on the wall. In laying stones in mortar their beds are to be so prepared that when settled down they shall rest close and full on the mortar. In handling the stones, care must be used not to injure the joints of those already laid; and in case a stone is moved after being set, and the joint thus broken, it must be taken out, the mortar must be cleaned thoroughly from the bed, and then the stone must be reset.

Wherever the Engineers shall so require, the stones shall have one or two steel dowels each, one and a quarter (1¼) inches in diameter, passing through them and into the stones below. The holes for the dowels shall be drilled through such stones before they are put into position on the walls, and after the stones are in place the holes shall be continued down into the under stones at least six (6) inches. The dowel pins shall then be set in, and the holes shall be filled with neat Portland cement grout. Clamps binding the several stones of a course together must be inserted when required by the Engineers. In such cases they shall be countersunk into the stones which they fasten together

The face stones must be accurately squared, jointed, and dressed on their beds and builds; and the joints must be dressed back at least twelve (12) inches from the face. Face stones are to be brought to a joint, when laid, of not more than three-quarters (¾) of an inch nor less than one-half (½) inch. The courses shall be not less than fifteen (15) inches in thickness, decreasing from bottom to top of wall; and they shall be well bonded. The face stones shall break joints at least twelve (12) inches. They may

be left rough, excepting only the stones forming the starling, which must be tooth-axed carefully to a uniform surface. The edges of face stones shall be pitched true and full to line, and on the corners of all piers a chisel draft of one and a half (1½) inches must be carried up from the base to the under side of the coping. No projection of more than three (3) inches from the edge of face stones shall be allowed. No stone with a hollow face shall be permitted in the work.

Each stretcher shall have at least twenty-four (24) inches width of bed for all courses of from fifteen (15) to twenty (20) inches rise, and for all thicker courses at least two inches more bed than rise. The stretchers shall have an average length of at least three and one-half (3½) feet, no stretcher being less than three (3) feet in length. Each header shall have a width of not less than eighteen (18) inches, and shall hold back into the heart of the wall the size that it shows on the face. The headers shall occupy at least one-fifth (1/5) of the whole face of the wall, and shall be, as nearly as practicable, distributed evenly over it and so placed that the headers in each course shall divide equally, or nearly so, the spaces between the headers in the course directly below. No header shall be less than three and a half (3½) feet long.

The tops of all piers shall be covered with copings, as shown on the drawings. All coping stones shall be neatly bush-hammer dressed on the face, top, and underside of projection; and they shall be set well and carefully on the walls, brought to one-quarter (¼) inch joints, and doweled, the dowels being well secured in and to the coping with grout. No coping stone shall be less than nine (9) square feet in plan.

P. 186. *Second-Class Masonry*

Second-class masonry shall consist of broken range rubble of superior quality, laid with horizontal beds and vertical joints on all exposed parts, with no stone less than eight (8) inches in thickness or eighteen (18) inches in width. In no case shall the bed of a stone be less than two (2) inches more than its build. The stones must decrease in thickness from bottom to top of wall, and must be bonded and leveled as well as can be done without hammer dressing. No mortar joints shall exceed one (1) inch in thickness. All corners shall have hammer-dressed beds and joints; and all corners and batter lines shall be run with an inch and a half (1½) chisel draft. At least one-fifth (1/5) of the stones in the face must be headers, distributed evenly throughout the surface. All stones must be laid on their natural beds. The backing shall be, preferably, of concrete as specified for first class masonry construction, but solid stone work will be permitted, provided that sufficient mortar be used to fill all voids, and that no two stones approach each other nearer than one-half (½) inch.

P. 187. *Mortar for First- and Second-Class Masonry*

This mortar shall be composed of one part of Portland cement to one and one-half (1½) parts of clean, sharp, dry, river sand, measurements being by volume and made loose. The sand and cement shall be mixed thoroughly dry, and after sufficient water is added to render the mass plastic, it shall be mixed and worked until it becomes of uniform consistency throughout. Mortar that has remained unused so long as to take an initial set shall not be employed on the work.

P. 188. *Pointing Masonry*

All masonry, both first and second class, is to be pointed so as to fill the joints solid. The surface of the wall is to be scraped clean, and the joints are to be freed from all loose mortar, then refilled solid by using proper ramming tools. All joints must be well wet before being pointed. Mortar used in pointing must be composed of one part of Portland cement and one part of sand, measurements being by volume and made loose.

P. 189. *Arch Culverts*

All arch culverts are to be built of either concrete or second-class masonry, according to the preceding requirements for piers, pedestals, and abutments, excepting only that in masonry constructions the arch ring shall be of first-class masonry.

P. 190. *Laying Masonry during Freezing Weather*

If it prove necessary to lay masonry during freezing weather, suitable precautions, satisfactory to the Engineers, shall be taken to prevent the mortar from freezing.

P. 191. *Back-Filling*

As soon as the masonry or concrete work thereof is completed, the space around each shore pier, pedestal, and abutment shall be filled with earth, preferably clay, thoroughly dampened, and well rammed in layers not exceeding six (6) inches in thickness. There shall be no direct payment for this back-filling, as its cost is to be covered by the price for excavation or that of masonry.

In case the boulders and gravel, or other material, at any channel-pier site be excavated before constructing the base thereof, the space around such completed pier shall be refilled to the original surface of the stream-bed to the satisfaction of the Engineers; and no allowance will be made the Contractor for such back-filling; but any heavy material placed around the said pier for protection above the said natural surface of the stream-bed shall be paid for as riprap, if there be a unit price provided therefor,

or otherwise as "Unclassified Work." Should, however, the Engineers deem that the excavated materials are unfit for back-filling and require the Contractor to use instead large stones or boulders, these are likewise to be paid for as riprap.

If any material from an existing embankment is removed by the Contractor in order to put in a pier or abutment, it shall be replaced by him at his own expense under this specification for back-filling, and he shall receive no payment therefor; but this clause shall not be interpreted as in any way obligating him to build at his own expense any more of the earthwork approaches.

P. 192. *Preparing and Placing Reinforcing Bars*

The reinforcement in the finished structure shall accurately conform in size and position to the requirements of the plans. Before being placed in the concrete, all reinforcement shall be free from loose rust, scale, or coating of any kind that would tend to reduce the bond between it and the concrete. All reinforcing bars shall be bent cold to the dimensions and forms shown on the drawings before they are placed in position. The bends shall be accurately made in a bending machine. All reinforcing bars shall be placed and held during construction accurately in the positions shown for them on the accompanying drawings. They shall be firmly bound and tied together by wire where they lap or cross, or shall be fastened by clips or other devices where specially called for. Each piece must be held rigidly and positively in position so that there shall be no displacement during the depositing of the concrete. Adjustment of bars during the placing of concrete will not be permitted. Where necessary, small blocks made of cement mortar may be used to support the reinforcing rods at proper distances from the forms.

P. 193. *Earth Embankments*

Beyond the abutments at each end of the bridge there will be earth embankments. These will be paid for per cubic yard in place above the present ground surface. The material used for the embankment is to be clay, sand, loam, gravel, or other earthy material free from pieces of wood, roots, or other foreign substances, and is to be placed in the embankments in layers one foot in thickness, the surface at all times being kept about level. Dumping from the top of the embankment down the side or end-dumping will not be allowed. Slopes are to be formed even and straight, correctly conforming to the slope stakes. The permissible depth, size, and location of borrow pits contiguous to the embankments shall be determined by the Engineers, but in all cases the borrow pits are to be continuous, forming drainage ditches. About ten (10) per cent volume above the net lines of embankment shall be placed in order to allow

for settlement and shrinkage; but the Contractor is to be paid only for the yardage contents of the net volume.

P. 194. *Timber Trestle Approaches*

There shall be furnished and constructed by the Contractor all the timber trestle work shown on the accompanying drawings. All the materials used therein must conform to the general requirements of these specifications, as must also the workmanship and finish thereon.

P. 195. *Pier Protection*

The Contractor shall furnish and construct the pier protection shown on the accompanying drawings. In respect to the materials, workmanship, and finish thereof, the general requirements of these specifications shall govern throughout.

P. 196. *Dolphins*

The Contractor shall furnish and build the dolphins shown on the accompanying plans. The piles therefor are to conform to the specifications for wooden piles given herein, and they are to be driven to such depths as the Engineers may direct. The piles of each dolphin are to be drawn together at the top, bolted, and wrapped with one (1) inch chain which is securely fastened with clips and hook-bolted to the piles.

P. 197. *Bank Protection*

The Contractor shall furnish all the materials for and construct to the satisfaction of the Engineers the bank protection shown on the accompanying plans. All the materials and labor therefor shall comply with the general requirements of these specifications.

V. 198. *Pile Dykes and Mattress Work*

When the bank protection consists of pile dykes, a complete general and detailed descriptive specification therefor should be drawn; and any unusual bridge materials employed, such as galvanized wire, should have their qualities defined.

As an example, the following is copied from an old specification for some dyke-work that did good service during sixteen years.

EXAMPLE

This dyke is to be composed of a main pile dyke about 2,150 feet long with cross-dykes at intervals of about 400 feet. The main dyke is to be principally on an easy curve, starting at the foot of Avenue J and running down to the line of the "Temporary Bridge." The said main dyke is to

consist of two rows of piles spaced six (6) feet centres in both directions, as shown on the accompanying drawings, capped with 8″ × 10″ timbers on flat running longitudinally, and braced with 6″ × 8″ timbers on flat both transversely and diagonally as shown. The rear row of piles is to be wattled, and a fifty (50) foot mat is to be built in front of, around, and behind the piles. Each cross-dyke is to consist of a single row of piles spaced six (6) feet centres, wattled, and capped with 8″ × 10″ timbers.

In general, the piles of the main dyke are to be cut off about three and one-half (3½) feet above extreme low water mark, but as the said dyke approaches the river bank at Avenue J the piles are to be gradually cut off higher up so that at the shore line they will be as high as the top of the bank. The piles of the cross-dykes are to be cut off so that their tops will lie in a plane, their elevation at the main dyke being the same as that of the piles of said main dyke, and the elevation of the piles at the other end about that of the top of the river bank. All piles are to be of white or burr oak, forty (40) feet long, from eight (8) to ten (10) inches in diameter at the tip and not less than fourteen (14) inches in diameter at the butt. All piles must be driven as closely as practicable to their proper position, and any piles which the Engineers may consider to be too much out of line will have to be removed and re-driven.

All timber for caps and bracing is to be of white oak of the best quality, free from wind-shakes, large knots, decayed wood, sap, or any defects that would impair its strength or durability. Cap timbers are to be 8″ × 10″ laid on flat and sized down to a uniform thickness. They are to be twelve (12) feet long with square butt joints, fitting tightly. The transverse braces are to be 6″ × 8″ by seven (7) feet long, laid on flat and dapped two (2) inches onto caps directly over the centres of the piles. The diagonal braces are to be 6″ × 8″ by nine (9) feet long, laid on flat, dapped two (2) inches onto caps, and pressing closely at ends against the transverse timbers. The daps on both the transverse and the diagonal timbers are in all cases to be so cut as to give a driving fit against the caps.

All steel used in the work must conform to the Manufacturers' Standard Specifications. The drift bolts connecting caps to piles are to be three-quarters (¾) of an inch in diameter and eighteen (18) inches long, driven into eleven-sixteenths ($^{11}/_{16}$) inch holes. There will be two drift bolts per pile. Spikes for connecting bracing timbers to caps are to be five-eighths (⅝) of an inch square and twelve (12) inches long. There are to be two (2) of them used at each end of each transverse or diagonal bracing timber. These spikes are to be driven into one-half (½) inch bored holes.

The wattling pieces are to be of good, sound, live willow, sycamore, or cottonwood, in lengths of either fourteen (14) or twenty-one (21) feet, having minimum diameters of three and one-half (3½) inches at the butt-end and one-half (½) inch at the tip. The said wattling pieces are to be driven down so as to touch each other, alternating large and small

ends, and reducing the area for passage of water by about fifty (50) per cent. The wattling is to extend everywhere from the river bed to the caps of the piles. All wattling is to be done before the caps are put on the piles.

After the piles are driven, but before they are capped, a continuous woven mattress from twelve (12) to fourteen (14) inches thick and fifty (50) feet wide is to be manufactured around the said piles over the entire length of the main dyke, the rear edge being located eight (8) feet from the centre line of the inner row of piles. All mattress work is to be woven, none but good, live, bar-growth, freshly-cut willow-brush being used. The style of weaving shall be the same as or similar to that employed upon the works of the United States Government. The mattress is to be continuously woven, the edge being bound with a single 5/8 inch galvanized strand steel rope, with the selvage of the mattress fashioned with a woven roll. At intervals of six (6) feet, longitudinal and transverse cables 3/8 inch in diameter shall be placed both on top and bottom of the mattress, and connected effectively with the selvage cables. Vertical ties of 9/32 inch wire rope at intervals of six (6) feet connecting top and bottom longitudinal and transverse cables shall be used and thoroughly tightened so that the said longitudinal and transverse cables shall bear tightly and intimately on the top and bottom of the mattress.

A grillage of willow, sycamore, or cottonwood poles, not less than twelve (12) feet in length or four (4) inches in butt diameter, shall be placed on top of the entire mattress work. They shall be spaced not more than six (6) feet from centre to centre, and shall be securely attached to the mattress work by 9/32 inch wire rope. Anchorage shall be supplied in the shape of native stone of an approved quality in the average proportion of twenty (20) pounds per square foot of mattress, there being more stone near the exterior edge of the mattress and between the piles than on the remaining portions. The distribution of this stone is to be made to the approval of the Engineers. The weight of the stones shall be from thirty (30) to one hundred and fifty (150) pounds each. At the up-stream end of the dyke the mattress is to be finished off, heavily loaded with rock and attached from the selvage edge by five-eighths (5/8) inch cables to dead-men in the bank in a manner to be approved by the Engineers. All wire rope used in the work shall be of the best quality and thoroughly galvanized. Workmanship throughout shall be good, skilled men only being employed.

After the completion of the dyke or any portion of it, each of the piles thereof is to be anchored down (so as to prevent its being pulled up by ice) with two seven (7) inch cast iron disc anchors, attached to a loop of nine-thirty-seconds (9/32) inch wire cable, and sunk into the river with a water-jet harpoon eighteen (18) feet below the bottom of the mattress. Instead of fastening these cables to the piles, they may be attached to the caps. They must be twisted so as to put a large initial

stress on each of them, and must be securely fastened to either the caps or the piles.

P. 199. *Adherence to Specifications in Bidding*

All the work herein outlined is to be done in strict accordance with these specifications, the accompanying plans, and such instructions as may be given from time to time by the Engineers. Bidders are hereby warned that they will be held strictly to the spirit of the specifications, and that it will be bad policy for any one to bid with the expectation that concessions will be made after the contract is closed, in order that the work may be cheapened or expedited. On this account bidders are respectfully requested not to complicate their tenders by submitting alternative bids based upon proposed changes in either plans or specifications, because such alternative bids will not be considered.

V. 200. *Scope of Contract*

In this clause should be stated clearly in detail everything that the Contractors shall have to do and to furnish, and where and how they are to deliver all the materials. If any parts are to be excluded from the contract, this should be indicated; and the division of the work among the various Contractors should be made perfectly clear. In this clause should be mentioned, even if the same be stated elsewhere, who is to attend to the work of removing the existing structure, if there be one to be removed, and at whose expense.

This is a most important clause, and it should receive the fullest consideration, to the end that there shall not be the slightest doubt in any bidder's mind as to exactly what he is and what he is not to furnish or perform. Special mention should be made of anchor bolts which are to be embedded in the masonry at the time of its construction, so as to make it clear whether they are to be included or not, because in some instances they are furnished by the Contractor for the substructure and in others by the Contractor for the superstructure. If they are to be furnished by the Manufacturer of the superstructure, and if they are needed before the rest of the metal, this should be stated, and the required date or dates for delivery thereof should be given. This last instruction applies also to any metal for the substructure that is to be furnished by the Manufacturer, such, for instance, as buried girders for piers.

Under the next heading, "Approximate Quantities of Materials," will be found a list of items that may enter into the construction of any bridge. It will be useful in preparing this clause, because its perusal will prevent any omission in the scope of the contract.

Example

The work to be done at present will be let under three contracts to one or more bidders.

A. Contract for Construction of Substructure: Shall include the furnishing of all materials and labor of every kind necessary to construct and fully to complete in every detail the three piers, the two abutments, and such embankments as may be required back of the abutments for the bridge, as shown on the accompanying plans Nos. 1*A*, 2, and 3, and described in these specifications.

B. Contract for Furnishing of Superstructure Metalwork: Shall include the furnishing f. o. b. cars at Trail, B. C., all of the metalwork required for the superstructure of the bridge, as shown on drawings Nos. 1*A*, 4, and 5, omitting only the towers, the hanger members for the span to be lifted, the machinery on the lifting span and on towers, the wire ropes, and the metal in counterweights.

C. Contract for Erecting of Superstructure Metalwork for Bridge as Simple Spans, as shown on drawings 1*A*, 4, and 5: Shall include the receiving, checking, unloading promptly and caring for all of the metalwork for the superstructure under Contract B, as it arrives at Trail; being responsible for all demurrage due to cars not being promptly unloaded; the erecting, riveting, adjusting, cleaning, furnishing the paint, and painting all of said metalwork; and the furnishing and placing of all other materials and building the entire superstructure complete and ready for traffic as a fixed span bridge, as shown on the accompanying plans Nos. 1*A*, 4, and 5 and described in these specifications.

At a later time two further contracts will be let under these specifications, as follows:

D. Contract for Furnishing of all Superstructure Metalwork and Machinery required to make one span operative as a lift span, as shown on drawings 1*A*, 6, 7, 9, and 10, and Sheets *M*1, *M*2, *M*3, *M*4, *M*5, *M*6, and *M*7: This contract shall include the furnishing f. o. b. cars at Trail, B. C., of all superstructure metalwork not furnished under Contract B, also all the necessary machinery, apparatus, motors, and electrical equipment.

E. Contract for Erecting of Superstructure Metalwork and performing all work necessary to convert the bridge into a lift bridge: Shall include the receiving, checking, promptly unloading, and caring for all the metal work required to make one span operative as a lift bridge (as shown on drawing 1*A*), the extra members on the lifting span, the towers, the machinery, apparatus, and electrical equipment on the lifting span and towers, and the metal in counterweights; being responsible for all demurrage due to cars not being promptly unloaded; the erecting, adjusting, riveting, cleaning, furnishing the paint, and painting of the new metal work; furnishing and applying oil for machinery and grease for guides; furnishing and applying dressing for cables; furnishing all materials and building complete the machinery house; furnishing all materials, except the enclosed steel, and building complete the concrete counterweights; performing all work necessary to put the bridge in perfect operating condition; and the furnishing of the necessary labor and mate-

rials, except electric current, and operating the bridge for one month after its completion, delivering it at the end of that period properly adjusted and in perfect order.

V. 201. *Approximate Quantities of Materials*

In this clause should be given, as accurately as practicable or convenient, a list of all the different materials required for the entire structure or structures and the quantity thereof for each kind. The grouping of the metal items should be arranged according to the pound prices of the different kinds of finished metalwork. It is well not to make too many groups, but care should be taken that the items included in each group be of approximately the same value per pound. If the division be simply ordinary structural steel and machinery metal, as is often the case, care should be taken to indicate clearly just where one class of metalwork ends and the other begins.

The following is a list of nearly every kind of material and work entering into the construction of the superstructure of a steel bridge:

1. Ordinary structural steel. (Can be divided into several items if desired.)
2. Reinforcing bars.
3. Machinery metal (this may all be grouped together or may be separated into component parts).
4. Nickel steel or other special alloy of steel.
5. Pavement for main roadway.
6. Concrete or reinforced concrete base for main roadway.
7. Concrete or reinforced concrete slab for sidewalks.
8. Untreated timber.
9. Treated timber.
10. Steel rails and their attachments (including special rail details and bonding).
11. Electric motors and other electric apparatus.
12. Gasoline engines.
13. Electric or other lighting.
14. Signals and switches for tracks.
15. Interlocking apparatus.
16. Wire ropes and their attachments.
17. Wire rope dressing.
18. Concrete or other materials in counterweights.
19. Machinery houses.
20. Wooden trestle approaches.
21. Draw protection.
22. Pile dykes.
23. Mattress work.
24. Removal of old spans.

25. Removal of shafts of piers, pedestals, and abutments.
26. Removal of bases of old piers, pedestals, and abutments.
27. Water pipes and apparatus for fire protection.
28. Hand-rails.
29. Shelter houses for pedestrians and operators.
30. Gates.
31. Smoke protectors.
32. Downspouts for water.
33. Waterproofing of floors and roofs.
34. Earth embankments for approaches.
35. Macadam on embankments.
36. Ties on embankments.
37. Curbing on embankments.
38. Trolley line.
39. Falsework to carry trains or other traffic.
40. Temporary bridge or trestle.
41. Untreated piles.
42. Treated piles.
43. Riprap.

The following is a list of nearly every kind of material and work that enter into the construction of the substructure of bridges:

1. Ordinary structural steel.
2. Reinforcing bars.
3. Concrete in shafts of piers, pedestals, and abutments.
4. First-class masonry in shafts of piers, pedestals, and abutments.
5. Second-class masonry in shafts of piers, pedestals, and abutments.
6. Untreated timber in cribs and caissons and in shells for bases of piers, pedestals, and abutments.
7. Concrete in cribs and caissons and in bases of piers, pedestals, and abutments.

(N. B.) Items 6 and 7 are frequently combined as mass in cribs, etc.

8. Granitoid.
9. Untreated timber piles **in and** below bases of piers, pedestals, and abutments.
10. Treated timber piles **in and** below bases of piers, pedestals, and abutments.
11. Reinforced concrete piles **in and** below bases of piers, pedestals, and abutments.
12. Untreated timber in pier protection.
13. Treated timber in pier protection.
14. Untreated piles in pier protection.
15. Treated piles in pier protection.
16. Pile dykes.
17. Mattress work.

18. Shafts of old piers, pedestals, and abutments to be removed.
19. Bases of old piers, pedestals, and abutments to be removed.
20. Old spans to be removed.
21. Falsework to carry trains or other traffic.
22. Temporary bridge or trestle.
23. Earth in fills back of abutments and in embankments.
24. Macadam on earth embankments.
25. Paving on earth embankments, including concrete base.
26. Sidewalk floors on earth embankments.
27. Hand-rails on earth embankments.
28. Ties on embankments.
29. Curbing on approaches.
30. Steel rails and their attachments.
31. Earth excavation.
32. Rock excavation.
33. Riprap.
34. Removal and rebuilding of sewers and other pipes and conduits.

The following is a list of nearly every kind of material and labor that enter into the construction of reinforced concrete bridges:

1. Ordinary structural steel.
2. Reinforcing bars.
3. Pavement for main roadway.
4. Concrete or reinforced concrete base for main roadway.
5. Concrete or reinforced concrete slab for sidewalks.
6. Steel rails and their attachments (including special rail details and bonding).
7. Electric or other lighting.
8. Signals and switches for tracks.
9. Interlocking apparatus.
10. Pile dykes.
11. Mattress work.
12. Removal of old spans.
13. Removal of shafts of old piers, pedestals, and abutments.
14. Removal of bases of old piers, pedestals, and abutments.
15. Downspouts for water.
16. Earth embankments for approaches.
17. Macadam for earth embankments.
18. Ties in earth embankments.
19. Curbing on earth embankments.
20. Trolley line.
21. Falsework to carry trains or other traffic.
22. Temporary bridge or trestle.
23. Untreated piles.
24. Treated piles.

25. Reinforced concrete piles.
26. Riprap.
27. Concrete in hand-rails.
28. Concrete in floor slabs and fascias.
29. Concrete in cross-girders and cantilever brackets.
30. Concrete in main girders.
31. Concrete in cross-walls or spandrel columns of arch spans.
32. Concrete in arches.
33. Concrete in shafts and copings of columns, piers, pedestals, and abutments.
34. Concrete in bases of piers, pedestals, and abutments.
35. Concrete in cribs and caissons.
36. Granitoid.
37. Sand filler.
38. Untreated timber in cribs and caissons and in shells for bases of piers, pedestals, and abutments.
39. Earth excavation.
40. Rock excavation.
41. Removal and rebuilding of sewers and other pipes and conduits.

This clause should either begin or finish with a paragraph similar to the following:

The figures given herein are only approximate, and neither the Purchaser nor the Engineers shall be held responsible in any way for their correctness.

EXAMPLE

The following are the approximate quantities of materials in the superstructure. They are to be used in comparing tenders, and are only approximate. They are not to be considered in any way as binding upon the Province or the Engineers:

Superstructure (without Lifting Details)

Metal in trusses, etc.	447,000 lbs.
Timber	120 M. ft. B. M.

Substructure

Metal in cylinders and bracing	268,000 lbs.
Concrete in cylinders and bracing	831 cu. yds.
Concrete in abutments	507 cu. yds.
Earth in embankments	1,125 cu. yds.

Superstructure Lifting Details, Machinery, and Towers

Metal in span	21,000 lbs.
Metal in towers	85,400 lbs.

Machinery on span......................	15,000 lbs.
Sheaves and bearings on towers...........	7,300 lbs.
Ropes................................	3,500 lbs.
Timber in walkways....................	4 M. ft. B. M.
Metal in counterweight..................	7,400 lbs.
Concrete in counterweight................	67 cu. yds.

V. 202. *Time of Completion*

The time or times of completion of the work should be distinctly stated so that there shall be no doubt whatsoever concerning the date at which any important division of the construction is to be finished. If the Purchaser is to furnish any of the materials to the Contractor, or if the latter's work in the field is dependent upon that of any other contractor, provision should be made in this clause for an extension of time in case of any delay caused by the non-delivery of such materials in due time or by the non-completion of the other contractor's work at the date or dates fixed; and the said extension of time should be limited to the actual time of delay, unless the said delay should run the Contractor into a season unfavorable to doing his field work, in which case an equitable extension should be arranged for.

Example

If this contract includes the construction of the substructure only, the entire work shall be completed within six (6) months from the date of the contract.

If this contract includes the construction of the substructure and the erection of the steel work and machinery, and the furnishing and erecting of all other materials required for the complete bridge, the entire work shall be finished within eight (8) months from the date of the contract, unless in the opinion of the Engineers, the Contractor be delayed by the non-delivery of the steel work and machinery f.o.b. cars at Black River Station, Louisiana, within five (5) months from the date of the contract, in which event the time for completion of the entire work shall be extended the amount of time the Contractor is, in the opinion of the Engineers, delayed by the non-delivery of the steel and machinery within the time specified.

If this contract shall include the manufacture and delivery f.o.b. cars at Black River Station, Louisiana, of the steel, machinery, and accessories for the superstructure, the entire work shall be completed and delivered at Black River Station, Louisiana, within five (5) months from the date of contract.

If this contract include the furnishing of all materials for and constructing the complete superstructure, the entire work shall be finished ready for service within eight (8) months from the date of the contract,

unless, in the opinion of the Engineers, any failure of the Contractor for substructure to complete his work in the specified time shall delay the erection of the superstructure, in which event the time for the completion of the entire work shall be extended the amount of time the Contractor is, in the opinion of the Engineers, delayed by the non-completion of the piers within the time specified.

If this contract include the furnishing of all materials, and the construction of the entire structure, the bridge shall be completed ready for service, to the satisfaction of the Engineers, within eight (8) months from the date of this contract.

P. 203. *Rate of Progress*

The Contractor shall commence work at such points as the Engineers may direct, and shall conform to their instructions as to the order and time in which the different parts of the work shall be done, as well as to the force required to complete the work at the date or dates specified. If, during the construction, it appear to the Engineers that the Contractor is not making proper progress, the Purchaser shall have the right, after giving the Contractor ten (10) days' notice in writing, to undertake himself, either by administration or by letting contract to other parties, the completion of the said work which is being thus neglected. Should the Purchaser's work cost less than what the Contractor would have been paid, the difference shall be paid to the Contractor; but, on the other hand, should it cost more, the difference shall be charged to the Contractor, and shall be taken out of the reserved ten (10) per cent or out of the bond. Under these circumstances the Purchaser shall have the right to enter upon and take temporary possession of the plant, tools, materials, and supplies of the said Contractor, or any part thereof. In case that the percentage of earnings withheld by the Purchaser be insufficient to make good the deficit, the Purchaser shall have the right to reimburse himself by the sale of the Contractor's plant; but, otherwise, the said plant shall be returned to the Contractor after the completion of the work.

If, in the opinion of the Engineers, the shopwork is being unnecessarily delayed or is about to be delayed because of non-delivery of any metal or because of the asserted inability of the shops to procure metal, the Purchaser shall have the right, after giving the Contractor five (5) days' notice in writing, to purchase the required metal in the open market, to deliver it to the shops, and to charge all costs for material and delivery against the Contractor.

I. 204. *Liquidated Damages and Bonus*

For each day (Sundays included) of delay **in completing the delivery of the materials (or in completing the construction)** covered in the con-

tract, all in accordance with the terms of these specifications and of the said contract, the Purchaser shall withhold permanently from the Contractor's total compensation the sum of .... ($ .....). The amount thus withheld is not to be considered as a penalty, but as liquidated damages, fixed and agreed to in advance by the contracting parties.

On the other hand, if the Contractor complete the delivery of the said materials (or construction) covered in the contract, all in accordance with the terms of these specifications and of the said contract, before the said specified time, the Purchaser shall pay to the Contractor as a bonus for his diligence and as a just acknowledgment of the value to the Purchaser of the time thus saved the sum of..........($ ....) for each and every day (Sundays included) that the said delivery (or construction) is completed in advance of the specified limit.

If, in the opinion of the Engineers, the Contractor be delayed by circumstances that are absolutely beyond his control, the Engineers may grant him an extension of time for the completion of his contract, but the determination of the amount thereof is to be left entirely to the said Engineers. In such a case the liquidated damages and the bonus are to be computed from the extended date instead of the date originally specified for completion.

If, *in any case or for any cause whatsoever*, the Contractor fail to finish the delivery of the materials (or completion of construction) within the time limit originally set in the specifications, the Contractor shall pay to the Purchaser for the Engineers a sum of money adequate to reimburse the latter for all expenses of every kind incurred by them because of the delay thus involved. This reimbursement of expense to the Engineers is under no circumstances to be waived; but the proper amount is to be deducted from the Contractor's payments.

I. 205. *Bond*

The Contractor will be required to give to the Purchaser a surety-company bond, satisfactory to the Purchaser, in the sum of .... dollars ($ ......), for the faithful performance of the contract and the specifications, and of all the terms and conditions therein contained, and for the prompt payment for all materials and labor used in the manufacture and construction of the structure (or structures), and to protect and save harmless the Purchaser because of injury to persons or property, caused by negligence, or claim of negligence, on the part of the Contractor, his agents, servants, or employees in doing the work or in connection therewith, also from violation, or claim of violation, of patent rights by the same, and from all loss of or damage to the property of the Purchaser.

The bond shall be so drawn as to permit of changes being made in the plans and specifications during the construction of the work, or of extending the time for its completion, without nullifying in any manner

whatsoever the validity of the said bond, custom or precedent to the contrary notwithstanding.

P. 206. *Payments*

Payments for work shall be made as follows:

On or about the first day of the month the Engineers will estimate the value of the work done and the materials furnished at site; and within fifteen (15) days thereafter ninety (90) per cent of the value thus determined, less previous payments, shall be paid to the Contractor in cash. Upon the completion of the entire work involved in the contract, and upon the acceptance of the same in writing by the Engineers, the balance due the Contractor for the entire work shall be paid to the said Contractor in cash.

Before, however, the final payment is made, the Contractor shall show to the Purchaser satisfactory evidence that all just liens, claims, and demands of his employees, or of parties from whom materials used in the construction of the work may have been purchased or procured, are fully satisfied; and that the materials furnished and the work done on the structure are fully released from all such liens, claims, and demands. If, too, during the progress of the work, it appear that the Contractor's bills for materials and labor are not being paid, the Purchaser shall have the right to withhold from the Contractor's monthly payments a sufficient sum or sums to guarantee himself against all losses from mechanics' and other possible liens, and to apply the said sum or sums to the payment of such debts.

P. 207. *Unclassified Work*

The Engineers shall have the right to require the Contractor to perform work or supply materials of any class not provided for in the specifications—such to be known as "Unclassified Work." In case such work or materials are ordered, they shall be paid for on the basis of actual cost to the Contractor of the materials and applied labor, plus twenty (20) per cent for his profit, no indirect expense of any kind being included. In case complete articles or products ready for installation are furnished by the Contractor instead of the constituent materials, the Contractor will be allowed for his profit ten (10) per cent on the cost to him of such articles. No allowance will be made for superintendence, insurance, or any other indirect expense, or for the use of tools or appliances. Satisfactory vouchers will be required from the Contractor for all expenses of unclassified work. No payment for any such work will be allowed unless it was ordered in writing by the Engineers before execution.

P. 208. *Bidders' Plant and Evidence of Experience*

At the time of opening of bids any or all bidders may be required to give satisfactory evidence that they have had actual experience in the

class of work for which they have tendered. Bids of inexperienced persons or companies and of those bidders who have failed in the past properly to perform other contracts may be rejected for such cause. Each bidder on substructure or erection of superstructure shall submit with his tender a full statement of the equipment he has available for use on the work for which he tenders.

V. 209. *Tenders*

In this clause there should be listed all the materials given in the clause entitled "Approximate Quantities of Materials," and a space should be left blank for the schedule price to be written in. Either at the head of the list or in each item, it must be clearly stated whether the prices cover material delivered at site, material in place, erection only, or otherwise. Directions should be given as to how the tenders are to be prepared and presented, and the date set for opening the bids should be stated.

Example

Bids will be received by the Chief Engineer of the Department of Public Works of the Province of British Columbia, at Victoria, B. C., up to noon of .... No bid will be considered which is received after that time.

Bids shall be made as follows:

First. For the substructure, as described in Paragraph A under Scope of Contract, tenders shall be made thus:

For metalwork in piers and bracing girders in place, and painting same, ... cents per pound.

For concrete in piers and bracing girders, ... dollars ($) per cubic yard.

For concrete in abutments, in place, ... dollars ($) per cubic yard.

For earth fill behind abutments, ... cents per cubic yard.

Second. Tenders for the furnishing of the superstructure metalwork, according to Paragraph B under Scope of Contract, shall be made as follows:

For furnishing f.o.b. cars at Trail, B. C., all of the superstructure metalwork for the fixed spans,..........cents per pound.

Third. For erecting the metalwork and completing the superstructure of the fixed spans, according to Paragraph C under Scope of Contract:

a. For erecting the metalwork and furnishing and applying the field coats of paint, ... cents per pound of metalwork.

b. For furnishing and erecting in place the timber floor, including the bolts, spikes, and fastenings for the timber,..........dollars ($) per M. ft. B. M. of timber in place.

Fourth. For furnishing the steel work, electrical equipment, and the

machinery necessary for making one of the fixed spans movable, bidders shall tender as follows, for material f.o.b. cars at Trail, B. C.:

a. For structural metalwork to be added to fixed spans in towers and for that in counterweights, ... cents per pound.

b. For all machinery on the movable span, ... cents per pound.

c. For main sheaves, shafts, and bearings on towers, ... cents per pound.

d. For suspending and operating wire ropes and their attachments, ... cents per pound.

e. For electric motor, electric controller and resistances, solenoid brake, switchboard, and appurtenances,............ dollars ($).

Fifth. Bidders for the erection of materials required to convert one fixed span into a movable span, according to Paragraph E of the Scope of Contract, shall tender as follows:

a. For unloading and erecting the structural metal to be added to the movable span, and that in the towers and in the counterweights, and for furnishing and applying the field paint to the same, ... cents per pound.

b. For unloading and erecting the machinery on the movable span, and for furnishing and applying the paint to the same, ... cents per pound of machinery.

c. For unloading and erecting the sheaves, shafts, and bearings on the towers, and for furnishing and applying the paint to the same,.......... cents per pound of metal.

d. For unloading and erecting the suspending and operating ropes and attachments, and for furnishing and applying the rope dressing for the same, ... cents per pound of metal.

e. For unloading and erecting the electrical equipment and for furnishing and putting in place all wiring and the conduits therefor, and all appurtenances necessary to make the electrical equipment complete and adequate for the satisfactory operation of the bridge, ... dollars ($).

f. For furnishing all materials for and erecting and painting the machinery house and walkways on the bridge, ... dollars ($).

g. For furnishing all the material for and erecting the concrete in the counterweights, ... dollars ($) per cubic yard.

V. 210. *Form of Proposal*

Occasionally it is necessary to have all tenders submitted on forms prepared by the Purchaser, in which case they should give the quantities of materials in a vertical line to the left of the page and two vertical blank rows for filling in the schedule prices and the corresponding totals.

In such cases there should be a clause similar to the following:

All proposals shall be made upon blanks furnished by ...., (or herewith enclosed, or accompanying these specifications).

I. 211. *Deposit Check and Forfeiture Thereof*

Each tender must be accompanied by a properly certified check for ....**dollars ($......) (or for .... (......) per cent of the total amount of the said tender)** made payable to .... The check of the successful bidder will be returned upon execution of contract and acceptance of bond. All other checks will be returned immediately upon execution of contract. Any bidder who refuses or fails within ten (10) days to enter into contract after it has been awarded to him will be declared irresponsible, and his check will be forfeited to the Purchaser. If any bidder neglect to deposit with his tender the required certified check, or if there be any irregularity in the check he deposits, or if the bank upon which his check is drawn be not solvent, his tender shall be rejected.

P. 212. *Integrity of Bid*

Each bid must be accompanied by an affidavit to the effect that the bid is genuine and not sham nor collusive, nor made in the interest nor on behalf of any person or corporation not named therein, that the bidder has not directly or indirectly induced or solicited any bidder to put in a sham bid or induced any other person or corporation to refrain from bidding, and that the bidder has not in any manner sought, by collusion, to secure to himself an advantage over other bidders. Any bid made without such affidavit, or in violation thereof, shall be absolutely void.

P. 213. *Withdrawal of Tender*

No tender can be withdrawn after it has been officially opened or after the date set in the specifications for opening it, unless it shall have been held unopened more than thirty (30) days after the said date set for opening.

P. 214. *Award of Contract*

As soon as possible after the award is made, a contract similar to that outlined on the accompanying form will be presented in duplicate to the successful bidder for his signature, after which both copies will be signed by the Purchaser, and one copy will be retained by each of the parties to the agreement.

Before any bidder is awarded the contract for the work, he must, if so requested by the Purchaser, furnish satisfactory proof of his financial and executive ability to deliver the materials and carry on the construction, as called for by these specifications. Failure so to do will involve the forfeiture of his deposit check.

P. 215. *Assigning or Subletting Contract*

The Contractor shall not assign nor transfer this contract nor sublet any part thereof without the written consent of both the Engineers and the surety on the Contractor's bond; and the written consent of his surety to such transfer or subletting shall be filed with the Engineers. No subcontract nor transfer of contract shall under any circumstances relieve the Contractor of any of his liabilities under this contract. Should any subcontractor fail to perform the work undertaken by him in a satisfactory manner, the Engineers may at their option annul and terminate such subcontract. Copies of all subcontracts that are permitted are to be delivered to the Engineers.

P. 216. *Rejection of Bids*

The Purchaser reserves the right to reject any or all bids

P. 217. *Return of Papers*

All papers submitted to bidders, excepting only those of the successful bidder, are to be returned to the Engineers upon demand.

I. 218. *Meaning of Terms*

Wherever in these specifications the term "Purchaser" is employed, it is understood to refer to ....

Wherever in these specifications the term "Engineers" or "Engineer" is employed, it is understood to refer to ...., or their (his) duly authorized representatives. Wherever the term "Inspector" or "Inspectors" is used, it is understood to refer to the representatives of the Engineers (Engineer).

Whenever in these specifications the term "this work" or "the work" is employed, it is understood to refer to all the work specified and mentioned throughout these specifications or indicated on the various plans accompanying the same.

Whenever the term "Contractor" is employed, it is understood to mean any person or corporation that may have entered into a contract with the Purchaser for this work or any portion thereof. Every reference to Contractor applies equally to all Contractors connected with the work, unless there is specific limitation to the contrary.

(Place and Date) ....

(Engineers).

CONTRACT

Between

Purchaser:

And

Contractor:

For

Dated .... at ....

(Engineers)

MEMORANDUM OF AGREEMENT, Made and signed this ....day of......................, at ...., by and between

the party of the first part, and sometimes termed in this agreement and in the specifications the "**Purchaser,**" and

the party of the second part, and sometimes termed in this agreement and in the specifications the "**Contractor.**"

WHEREAS.

WHEREAS, The **Contractor** has, under date of....................., made a satisfactory tender for

NOW THIS AGREEMENT WITNESSETH:

First. The **Contractor,** for and in consideration of certain payments to be made to him as hereinafter specified, hereby covenants and agrees to provide, at his own cost and expense, all labor, machinery, plant, tools, and appliances, and to

all in accordance with the **Plans** and **Specifications** hereunto annexed and made a part hereof, and will fully finish and complete the same by

but, if, in the opinion of the **Engineer,** the **Contractor** be delayed or prevented in the prosecution of the work by conditions absolutely beyond the control of the **Contractor,** additional time for completion of the contract will be allowed, and the amount of such additional time will be determined and fixed solely by the **Engineer.**

Second. The **Contractor** shall start the work of construction as soon as practicable after the signing of the contract, and shall carry on the work with adequate diligence to ensure its completion within the time specified.

Third. In consideration of the performance by the **Contractor** of his covenants and agreements, as herein set forth, the **Purchaser** hereby covenants and agrees to pay the **Contractor** as follows:

In case the **Engineer** require the **Contractor** to perform work or to supply materials of a class not included and covered in the above list of items nor, in the opinion of the **Engineer,** described or implied as included in the above list by the plans and specifications, such materials and work shall be paid for as provided in the clause for **Unclassified Work** in the attached specifications.

* No payments, either partial or final, are to be made for any material which is to be used for falsework or plant; but payment is to be made only for materials which are left permanently in the finished structure and form a part of it. The **Engineer**

* This sentence may occasionally have to be modified or omitted.

may, at his discretion, allow temporary partial payments in advance of the permanent work as materials for plant and falsework are employed, but the **Contractor** shall have no right to demand such compensation.

Fourth. The schedule prices to be employed in making partial payments for all work as it progresses are to be determined by the **Engineer.**

Fifth. All material paid for by the **Purchaser** shall be deemed to have been delivered to, and to have become the property of the said **Purchaser,** but the **Contractor** hereby agrees to store it and to become responsible for it during the continuance of this agreement. If any of it be lost, damaged, or destroyed by floods, washouts, or fires, or by any other means whatsoever, the **Contractor** shall repair or replace the same at his own expense and to the satisfaction of the **Engineer.**

Sixth. If the **Contractor** fail to complete the work within the time specified, and if the **Purchaser** shall nevertheless permit the said **Contractor** to proceed, and continue, and complete the same, as if such time had not lapsed, such permission shall not modify nor waive in any respect any forfeiture or liability of the **Contractor** for damages arising from such non-completion of said work within the time specified, and covered by the "Liquidated Damages" clause of the specifications; but such liability shall continue in full force against the said **Contractor,** as if such permission had not been granted.

Further, if the **Contractor** fail to complete the work within the time specified, no partial estimates will be rendered and no payments will be made after the date specified for completion until the **Contractor** shall deliver to the **Engineer** for each and every such partial payment the written consent of the **Contractor's Surety,** permitting such payment to be made without affecting the validity of the Bond.

Seventh. No change or alteration shall be made in the terms or conditions of this agreement without the consent of both parties hereto in writing; and no claim shall be made or considered for any additional or unclassified work unless the same shall be authorized and directed in writing by the **Engineer.**

Eighth. The **Contractor** hereby assumes the risk of the occurrence of delays in the prosecution and completion of the work embraced in this contract; and the amounts hereinbefore mentioned to be received by the **Contractor** in payment for the work include and cover that risk, and therefore the **Contractor** shall be entitled to no additional compensation on account of any such delays.

Ninth. The **Contractor** hereby agrees that he will at all times keep within his control the work covered in this contract and will not assign or sublet all or any portion of it without the written consent of the **Purchaser.**

Tenth. The decision of the **Engineer** shall at all times control as to the interpretation of drawings and specifications for the work; but if either the **Purchaser** or the **Contractor** shall consider himself aggrieved by any such decision of the **Engineer** he may require the dispute to be finally and conclusively settled by the decision of arbitrators, one to be appointed by the **Purchaser,** and a second by the **Contractor.** In case the two arbitrators thus chosen fail to agree, a third arbitrator shall be appointed by

By the decision of these arbitrators, or by that of a majority of them, both parties to this agreement shall be finally bound.

Eleventh. The **Contractor** is to indemnify the **Purchaser** against all liability or damages on account of accidents occasioned, or claimed to be occasioned, by the omission or negligence of himself, his agents, or his workmen during the continuance of this agreement, and against all claims for royalties on patents; therefore it is hereby agreed that the **Contractor** shall be promptly and duly notified in writing by the **Purchaser** of the bringing of any suit or suits on such accounts against the **Purchaser,** and shall be given the option of assuming the sole defense thereof. It is also agreed that the **Contractor** is to pay all judgments obtained by reason of accidents or patents in any suit or suits against the **Purchaser,** including all legal costs, court expenses, and other like expenses.

Twelfth. The **Contractor** further agrees to give to the **Purchaser,** and to maintain in force during the continuance of this contract, a surety-company bond, satisfactory to the **Purchaser,** in the sum of .... dollars ($........), for the faithful performance of this contract and the specifications, and of all the terms and conditions therein contained, and for the prompt payment for all materials and labor used in the manufacture and construction of the structures, and to protect and save harmless the **Purchaser** from all claims on account of patents and from all damages to persons or property caused by the negligence or claim of negligence on the part of the **Contractor,** his agents, servants, or employees in doing the work or in connection therewith, and from injury to or loss of materials paid for by the **Purchaser** either partially or in full before the completion and acceptance of the construction or constructions.

Thirteenth. The word "**Engineer**" or "**Engineers**" as used in this Contract and in the Specifications shall mean ...., the Consulting Engineers of
or their duly authorized representative.

IN WITNESS WHEREOF, the parties to this agreement have hereunto set their hands and seals.
Dated the day and year first herein written.

....	**Purchaser.**
....	**Witness of Purchaser's Signature.**
....	**Contractor.**
....	**Witness of Contractor's Signature.**

CLAUSE INDEX OF CHAPTER LXXIX

CHAPTER LXXX

GLOSSARY OF TERMS

THE dimensions to which the following glossary of technical terms used in all branches of bridgework and in its allied constructions has attained are a surprise to all concerned in its preparation. While it is intended to cover only those technical words that are employed in bridge engineering and construction, it includes all lines thereof, from the theory given in the technical schools, through the designing, manufacture of metal, and all other bridge materials, shopwork, inspection, and construction—up to the completion of the finished structure and all the accessory works, such as approaches, shore protection, operating machinery, lighting, and fire protection—also even the maintenance and operation of finished structures. On this account, many special words used in mechanical and electrical engineering and in water supply have necessarily been inserted. It has been the aim of the author to include, regardless of their evident crudity, the special nomenclature of the workmen which is not to be found in the dictionaries or other glossaries. Elaborate, though, as this glossary certainly is, it is possible that there will be found omitted some words of more or less importance, notwithstanding the extreme care that has been taken to overlook nothing. While making it complete, the aim has been to avoid padding by the exclusion of words that would be of no practical value under any circumstances. Occasionally some far-fetched term has been discarded, mainly because of the inability of all concerned properly to define it; but such cases were rare. Those simple, common, semi-technical words in everyday use, which form a part of the vocabulary of the general public as well as of bridge engineers and constructors, have been omitted, unless a special reason, such as given below, has made it necessary to include them.

Double words, like "Chinese Windlass," are defined nearly always under the noun, but a cross reference is made under the adjective. Hyphenated words are defined under the letter of the first word. Phrases are given under the dominating or most distinctive word, and are cross-referenced under the subsidiary word or words.

A group of words related to a single word appears as sub-heads under that word. In some instances, in order to preserve the uniformity of arrangement, it has been necessary to define apparently simple words in order to introduce the sub-headings in their proper places. It is believed that the grouping of sub-headings in this manner will afford the reader

a better grasp of the extent and ramifications of a subject than could be gained without such a classification.

The beginning of the preparation of this glossary dates back more than a dozen years to the time when the author conceived the idea of preparing a dictionary of technical engineering terms in English, French, German, and Spanish. The task proved to be too great for the time that could be spared, and hence was abandoned; but the list of technical terms collected for the purpose formed a good nucleus for this chapter. Later, after the writing of the book was begun, the author enlarged greatly the first list by selecting words from bridge specifications and from books on all subjects relating to steel metallurgy and to bridge engineering and construction, and also by having his numerous field engineers send in lists of special words and phrases used in erection. After all the terms were thus collected and placed in proper order, it was found that they numbered about four thousand, but the author excluded some four hundred of them, mainly because of their not being sufficiently unusual or strictly technical; after which the list was typewritten and made ready for the preparation of the definitions. This last work was done principally by the author's son and future partner, N. Everett Waddell, Esq., C.E.,* aided by Robert C. Barnett, Esq., C.E.,† and the author's brother, R. W. Waddell, Esq., C.E. Finally, the work was checked and revised by the author in person, who desires here to acknowledge with many thanks the valuable assistance and the careful and painstaking work of the three gentlemen just mentioned. They not only defined the old list of terms furnished to them, but also enlarged it fully one-third, mainly by adding derivatives, the number of terms actually defined being about five thousand, and the number cross-referenced about three thousand.

In view of the large amount of labor and the great care expended on the preparation of this glossary, it is ardently hoped by all concerned in its preparation that it will prove of real service to the engineering profession.

GLOSSARY

A

Abacus.—The upper member of the capital of a column.

Abscissa.—A term in rectangular coordinates referring to the horizontal distance of any point from the vertical axis.

Abutment.—That part of a pier from which an arch springs. A structure sustaining one end of a bridge span and at the same time supporting the embankment which carries the track or roadway.

Straight Abutment.—An abutment that has only one wall, which is generally at right angles to the longitudinal centre line of the structure.

Stub Abutment.—Same as "Straight Abutment," *q.v.*

T-Abutment.—A straight or stub abutment with a stem running back into the fill.

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* Now junior member of the firm of Waddell and Son, Consulting Engineers.

† Now Associate Engineer of Waddell and Son.

Abutment.

U-Abutment.—A straight abutment with additions of two wing walls at right angles to the face.

Wing Abutment.—An abutment similar to a U-abutment except that the two wings make angles with the face of from thirty to forty-five degrees.

Abutment Line.—See "Line."

Abutting Joint.—See "Joint."

Acceleration.—The increase in velocity which takes place in a unit of time.

Acid Open-Hearth Furnace.—See "Furnace."

Acid Steel.—See "Steel.

Activity of Cement.—See "Cement."

Actual Horse-power.—Same as Brake Horse-power. See "Horse Power."

Adhesion.—The force which holds together two bodies placed in close contact with each other.

Adiabatic Curve.—See "Curve."

Adjustable Eye-bar.—See "Eye-bar."

Adjustable Key.—See "Key."

Adjustable Member.—See "Member."

Administration.—The direction or oversight of any office, service, or construction; or the management of public affairs.

Adulterant.—A substance substituted partially for another without acknowledgment.

Adulteration.—The partial substitution of one substance for another without acknowledgment.

Advancing-load Stress.—See "Stress."

Adze.—A hand tool, having a curved cutting edge perpendicular to the handle, used for dressing the surfaces of timbers or stones.

Aeration Jet.—See "Jet."

Aggregate.—The inert material such as sand, broken stone, etc., with which the cement or other adhesive material is mixed to form a concrete or mortar.

Air-blast.—An air current forced upon a fire to stimulate combustion.

Air Brake.—See "Brake."

Air Chamber.—See "Chamber."

Air Compressor.—See "Compressor."

Air Current.—See "Current."

Air Cushion.—See "Cushion."

Air Cylinder.—See "Cylinder."

Air Dolly.—See "Dolly."

Air Gauge.—See "Gauge."

Air Gun.—See "Gun."

Air Hammer.—See "Hammer."

Air Hoist.—See "Hoist."

Air Hose.—See "Hose."

Air-lift.—A hoisting apparatus that operates by means of compressed air.

Air Line.—See "Line."

Air-lock.—An air-tight, double-door antechamber of a caisson used for passing workmen or materials into or out of the caisson and to regulate the air pressure during such passage.

Air Piston.—See "Piston."

Air Pressure.—See "Pressure."

Air Pump.—See "Pump.

Air Reamer.—See "Reamer."

Air-receiver.—A reservoir in which compressed air is received and stored.

Air Riveter.—See "Riveter."

Air-setting.—Hardening by exposure to air. Usually applied to cement.

Air Shaft.—See "Shaft."

Air Slake.—See "Slake."

Air Valve.—See "Valve."

Alidade.—The horizontal plate in a transit which carries the verniers, the level bulbs, and the standards, and which revolves about the graduated limb: an attachment on many instruments for measuring angles. A straight edge, having a telescope mounted thereon, used in plane table surveying.

Alignment.—The state of being in line; the ground plan of a railway or other road in contradistinction to the grades or profile.

Alligator Riveter.—See "Riveter."

Alligator Wrench.—See "Wrench."

Allowable Bearing Pressure.—See "Bearing."

Alloy.—A substance consisting of two or more metals mixed together, or non-metallic bodies mixed with metals, in intimate solution or combination with one another, forming, when melted, a homogeneous fluid.

Alternate Layout.—See "Layout."

Alternating Current.—See "Current."

Altitude.—Height; the degree or amount of elevation above the foundation or ground.

Aluminum.—A white metal with high tensile strength and low specific gravity. Used for purifying steel.

Aluminum Bronze.—An alloy of copper containing about ten per cent of aluminum.

Ambiguous Stress.—See "Stress."

American Locomotive.—See "Locomotive."

Ammeter.—An instrument for measuring or estimating in amperes the strength of an electric current. An ampere-meter.

Amorphous.—Without regard for definite form; uncrystallized, structureless.

Amortization.—A method for liquidating a debt by making annual payments to a sinking fund which in a given time with the accumulated interest becomes equal to the debt.

Amount.—The sum of the principal plus accrued interest for a given time. In the case of a sinking fund involving periodic deposits of money, the amount of such fund is the sum of the "amounts" of the deposits.

Amplitude of Vibration.—See "Vibration."

Anchor.—An apparatus which holds a floating object to the bottom, or any device for holding an object to the ground or to other fixed objects.

Chinese Anchor.—A rectangular box filled with rocks, used for anchoring in swift currents. A sling, or bridle, is attached to the box, and to this a float is fastened.

Mushroom Anchor.—An anchor made in the shape of a mushroom—used on muddy bottom.

Anchorage.—A device for anchoring down any part subjected to uplift, such as the end of the anchor arm of a cantilever bridge.

Anchor Arm.—The end portion of a cantilever bridge extending from one of the main piers to an anchor pier.

Ancher Bar.—See "Bar."

Anchor Bolt.—See "Bolt."

Anchor Pier.—See "Pier."

Anchor Pile.—See "Pile."

Anchor Plate.—See "Plate."

Anchor Shackle.—See "Shackle."

Anchor Span.—See "Span."

Angle.—The amount of divergence between two intersecting, straight lines. The term is also applied to an angle-iron section, *q.v.*

Bulb Angle.—An angle-iron section in which one leg has a bulb on one end.

Angle.

Clip Angle.—A short attaching angle that takes a portion of the stress of any main member; also termed a "lug-angle."

Connecting Angle.—An angle-iron used for connecting two pieces.

Flange Angle.—One of the upper or lower chord angles in a girder.

Flashing Angle.—An angle to which flashing is attached.

Lacing or Lattice Angle.—An angle used in latticing, *q.v.*

Lug Angle.—Same as "Clip Angle," *q.v.*

Reentrant Angle.—An angle in which the vertex points inside the figure of which it forms a part.

Seat Angle.—A short angle riveted to a column to support temporarily a beam during erection.

Shelf Angle.—Same as "Seat Angle," *q.v.*

Starred Angles.—A pair of angles placed corner to corner with legs outstanding and held in position by tie-plates riveted thereto at intervals.

Stiffening Angles.—Angles riveted to the web of a girder to stiffen it against buckling.

Thrust Angle.—A short angle inserted between the outstanding legs of a column at the bottom of the cantilever bracket to carry the thrust from the latter to the cross-girder. An angle member in traction bracing.

Angle Clip.—Same as "Clip Angle," *q.v.*

Angle-iron.—A rolled piece of steel having a cross-section shaped into a right angle.

Angle Joint.—See "Joint."

Angle Lacing.—See "Lacing."

Angle Lug.—Same as "Clip Angle," *q.v.*

Angle of Friction.—See "Friction."

Angle of Repose.—See "Repose."

Angle of Rupture.—See "Rupture."

Angle of Torsion.—See "Torsion."

Angle of Twist.—Same as "Angle of Torsion," *q.v.*

Angle Strut.—See "Strut."

Angular Fracture.—See "Fracture."

Angular Strain.—Same as "Torsional Strain," *q.v.*

Angular Velocity.—See "Velocity."

Anneal.—To reduce the brittleness and increase the ductility of metal by heating to a certain temperature, then cooling slowly in air or oil.

Annealing Furnace.—See "Furnace."

Annuity.—A regular, yearly payment of a uniform sum of money.

Anvil.—A heavy block of steel on which metals may be hammered, shaped, or forged.

Anvil Vise.—See "Vise."

Apex.—The intersection of a web member with a chord or flange; also called a panel point.

Apex Load.—See "Load."

Apparent Stress.—See "Stress."

Approach.—The construction leading to the end of a bridge.

Apron.—A device to protect a river bank or river bed against scour; a shield.

Ice Apron.—An ice breaker, or starling, placed on the up-stream end of a bridge pier to protect it from the moving ice.

Aqueduct.—An artificial canal for the conveyance of water, either above, on, or under the ground.

Arbitration Test Bar.—See "Bar."

Arc.—A portion of a curve. An arch.

Arch.—Any bow-like curve, structure, or object, usually having the convex side upward, generally spanning an opening and producing horizontal as well as vertical reactions.

Blind Arch.—An arch in which the opening is walled up.

Arch.

Braced Arch.—An open-work truss in the form of an arch.

Catenary Arch.—An arch which takes the form of an inverted catenary, *q.v.*

Circular Arch.—An arch which takes the form of a portion of a circle.

Crown Thrust of an Arch.—The thrust or compression existing at the crown of an arch due to the loading.

Elastic Arch.—An arch designed on the basis of the elastic theory of materials.

Elliptical Arch.—An arch having the form of a semi-ellipse.

Flat Arch.—An arch in which the intrados is straight; an arch of low rise.

Geostatic Arch.—An arch which has a curve of such nature that the vertical pressure is proportional to the depth below a fixed horizontal plane, and the horizontal pressure bears to the vertical pressure a fixed ratio depending on the nature of the superincumbent materials.

Groined Arch.—An arch in which the curved intersections, or arrises, of simple vaults cross each other at any angle.

Hinged Arch.—An arch which has one or more hinged joints.

Inverted Arch.—An arch having its intrados below the axis or springing line.

Jack Arch.—An arch limited in thickness to that of one brick.

Laminated Arch.—A beam, having the form of an arch, constructed of several thicknesses of planking bent to shape and bolted together.

Lenticular Arch.—An arch which has a rib composed of two lens-shaped trusses.

Linear Arch.—A linear arch is the equilibrium polygon for the system of loads applied to the physical arch. In an actual arch the resistance line is the linear arch for the actual loading.

Melan Arch.—A type of reinforced concrete arch in which ribs of rolled I-beams, or built up lattice girders, spaced two or three feet centres, are used to strengthen the concrete arch barrel.

Monier Arch.—An arch in which the reinforcement consists of wire netting, one net being placed near the intrados and one near the extrados.

Multi-centered Arch.—An arch having an outline composed of a series of circular arcs with different radii, giving an approximation to an ellipse. These arcs are symmetrically disposed about a vertical axis and occur in odd numbers.

Oblique Arch.—An arch in which the axis is not perpendicular to the central plane of the structure.

Open Spandrel Arch.—An arch in which the roadway is carried on spandrel columns or cross-walls.

Relieving Arches.—Arches which are built at the back of a retaining wall with their axes perpendicular to the wall, in order to relieve the structure from a portion of the lateral thrust, and to increase the resistance to overturning by the additional weight of masonry and its superposed earth load.

Right Arch.—An arch in which the faces are perpendicular to the axis of the soffit.

Rise of an Arch.—The vertical distance from the springing line to the highest point of the intrados.

Segmental Arch.—A circular arch in which the intrados is less than a semi-circle.

Skew Arch.—Same as an "Oblique Arch," *q.v.*

Solid Arch.—An arch which has no openings or deep recesses in its arch barrel, and which is composed of one material or aggregate.

Solid Spandrel Arch.—Same as "Spandrel Filled Arch," *q.v.*

Spandrel Braced Arch.—See "Spandrel Braced."

Spandrel Filled Arch.—An arch in which the spandrels are filled with earth or other materials.

Striking of Arch.—Knocking out the wedges and lowering the centres, thus making the arch self-supporting.

Three-hinged Arch.—An arch hinged at the piers, or abutments, and at the crown.

Arch.

Thrust of Arch.—The horizontal reaction of an arch against its abutment. Also the resulting pressure normal to the face of a radial section of an arch ring.

Two-hinged Arch.—An arch hinged only at the piers or abutments.

Arch Barrel.—Same as "Arch Ring," *q.v.*

Arch Bridge.—See "Bridge."

Arch Buttress.—A flying buttress; an arch springing from a buttress or pier.

Arch Centre.—A temporary structure for supporting an arch while in the process of construction.

Arch Culvert.—See "Culvert."

Arch Depth.—See "Depth."

Arched Girder.—See "Girder."

Arch Rib.—A rigid curved beam either solid or built up of members like a truss.

Arch Ring.—That portion between the extrados and intrados of an arch, sometimes called an "Arch Barrel."

Arch Span.—See "Span."

Arch Stone.—Same as "Voussoir," *q.v.*

Arch Truss.—See "Truss."

Architect's Rod.—See "Rod."

Architect's Scale.—See "Scale."

Area.—The amount of surface included between certain closed boundary lines; any particular extent of surface, region, or tract.

Catchment Area.—Same as "Drainage Area," *q.v.*

Drainage Area.—The area drained by a stream or streams.

Effective Area.—The gross area of a section less that lost by the rivet holes or the pinholes; the net area.

Moment Area.—Sometimes called area moment. The area enclosed by a moment curve. See also "Moment-Area Method."

Sectional Area.—The area enclosed by the periphery of a section of a piece or member.

Area Moment.—Same as "Moment Area," *q.v.*

Argillaceous.—Containing a certain amount of clayey matter, such as shale.

Arithmetical Progression.—See "Progression."

Arris.—The edge or ridge formed by the intersection of two surfaces.

Artificial Portland Cement.—See "Cement."

Asbestos.—A white, gray, or green-gray fibrous variety of hornblende; usually one containing but little aluminum, as tremolite or actinolite. At times it is called earth flax, mountain cork, and amiantus. It is considered fireproof.

Asbestos Packing.—See "Packing."

Asbestos Paper.—See "Paper."

Ashlar.—Large squared blocks of stone. Also frequently used for cut-stone masonry.

Axed Ashlar.—Ashlar blocks which have been finished or dressed with an axe.

Broken Ashlar.—Cut-stone masonry formed of ashlar blocks but laid so that the horizontal joints are discontinuous.

Dressed Ashlar.—Ashlar blocks in which the faces have been dressed or smoothed off to a greater or less degree.

Rough Ashlar.—Ashlar blocks in which the faces are left rough. This term is also used, rather illogically, for squared range-masonry.

Small Ashlar.—Ashlar blocks less than one foot thick.

Tooled Ashlar.—Ashlar blocks that have been dressed on the face with a mason's tool.

Ashlar Masonry.—See "Masonry."

Asphalt.—A bituminous material employed for covering roofs, filling between paving blocks, forming surfaces of roads, etc.

Asphalter.—One who covers surfaces with asphalt.

Asphalt Furnace.—See "Furnace."
Asphaltic Mastic.—See "Mastic."
Asphalt Rock.—A limestone impregnated with bituminous material.
Asphaltum.—Same as "Asphalt," *q.v.*
Assay.—A test of the composition, purity, weight, etc., of metals or metallic substances such as ores or alloys.
Assay Balance.—See "Balance."
Assay Furnace.—See "Furnace."
Assembling Bolt.—See "Bolt."
Assembling Hoist.—See "Hoist."
Assistant Engine.—See "Engine."
Atlantic Locomotive.—See "Locomotive."
A-Truss.—See "Truss."
Auger.—An instrument for boring holes larger than those made by a bit or gimlet; consisting of a helix with cutting prongs or edges.
Crank Auger.—An auger operated by turning a crank; used on metal or wood.
Post-hole Auger.—A large size hand tool for boring holes in earth.
Ship Auger.—An auger with a long shank in which two cranks are formed.
Single Lip Screw Auger.—An auger which has a bit with only one lip or cutting edge.
Auger Bit.—A small auger used with a brace or a bit-stock.
Automatic Gate.—See "Gate."
Automatic Switch.—See "Switch."
Average End-Area Formula.—A formula for finding the approximate volume of a prismoid. Thus:

$$V = \left(\frac{A_1 + A_2}{2}\right) l$$

where V = volume,
A_1 = area of one base,
A_2 = area of the other base,
and l = the perpendicular distance between bases.

Average Haul.—See "Haul."
Awl.—A sharp, pointed tool used for punching small holes in wood or leather without removing the material itself.
Brad Awl.—A short non-tapering awl, with the cutting edge on the end, for making holes in wood to receive brads, screws, etc.
Scratch Awl.—Same as "Scribing Awl," *q.v.*
Scribing Awl.—A straight, sharp-pointed awl used for making lines on wood and metal; sometimes called a scratch-awl.
Ax or Axe.—A hand tool used for hewing timber and chopping wood, also in some forms employed for surfacing stone.
Broad Axe.—An axe with a broad blade on one side and a hammer head on the other.
Double-bitted Axe.—A double-bladed axe.
Hand Axe.—A small, short-handled axe.
Pick Axe.—A hand tool similar to a pick, but having broader blades set at right angles to each other.
Poll Axe.—An ax with a rounding blade on one side and a blunt head or pole on the other. It is the most common form of axe.
Tooth Axe.—A mason's tool with a double wedge-shaped head and teeth on the cutting edges.
Axed.—A form of stone dressing. See "Dressing."
Broken-Axed.—A form of stone dressing. See "Dressing."
Tooth-Axed.—A form of stone dressing. See "Dressing."
Axed Ashlar.—See "Ashlar."

Axed Dressing.—See "Dressing."

Axed Stone.—See "Stone."

Axe Hammer.—See "Hammer."

Axial.—Pertaining to or of the nature of an axis.

Axial Stress.—See "Stress."

Axiom.—A self evident principle or fact.

Axis.—A line about which a figure or a body is symmetrically arranged, or about which such a figure or body rotates. A principal line through the centre of a figure or solid. A fixed line along which distances are measured or to which positions are referred.

Eccentric Axis.—An axis that does not pass through the centre of gravity or the centre of figure of the body considered. The axis about which an eccentric revolves.

Longitudinal Axis.—An axis in the longitudinal direction of the figure or body considered, and generally passing through the centre of gravity or the centre of figure.

Neutral Axis.—The trace of that plane in a beam where there is no tension or compression and where no deformation takes place.

Polar Axis.—An axis at right angles to the plane of rotation.

Axis of Gravity.—See "Gravity."

Axis of Symmetry.—See "Symmetry."

Axis of Pressure.—See "Pressure."

Axis of Resistance.—See "Resistance."

Axis of Rotation.—See "Rotation."

Axle.—A pin or spindle about which any wheel or member revolves.

Blind Axle.—An axle that does not communicate power; also called a dead axle.

Driving Axle.—An axle which communicates motion to other parts of a machine. The axle of a locomotive which receives power from a steam piston through connecting rods.

Thrust Axle.—An axle subjected to a longitudinal thrust.

Axle Concentration.—See "Concentration."

Axle Load.—See "Load."

Azimuth.—The angular position of an object referred to a meridian.

B

Babbitt Metal.—See "Metal."

Baby.—A bundle of willows or other brush tied together and enclosing small rock, thrown into a stream to protect the bank. More properly termed a "fascine."

Back-filling.—See "Filling."

Backing.—A course of masonry resting on the extrados of an arch; the earth filling behind an abutment; the interior filling of any stone masonry construction.

Backing-out Punch.—See "Punch."

Back-lash.—The reaction or tendency to work backward in a pair of gears when subjected to a sudden load. The loose play between the teeth of intermeshing gears.

Back-sight.—A level observation, or sighting back, to a turning point or bench mark of known elevation. A transit observation on a previously located point in the rear. A fixed object in the rear which is sighted upon from time to time to check the orientation of the transit.

Back Speed.—The second speed gear of a lathe.

Back Stay.—See "Stay."

Back Truck Locomotive.—See "Locomotive."

Balance.—An instrument used to determine weights.

Assay Balance.—A very sensitive, accurate balance used by assayers for weighing exceedingly small quantities of materials.

Locomotive Balance.—See "Locomotive Balance."

Balance.

Spring Balance.—An apparatus for weighing articles by noting the compression of a helical spring.

Balance Beam.—The graduated bar of a balance.

Balance Block.—See "Block."

Balance Crane.—See "Crane."

Balanced Load Stress.—See "Stress."

Bale Hook.—See "Hook."

Balk.—A large beam of timber. Sometimes written "baulk."

Ball and Socket Joint.—See "Joint."

Ballast.—Gravel, broken stone, slag, or other road material put between the ties of a railroad to prevent them from slipping and to give solidity to the road.

Ballasted Floor.—See "Floor."

Ballast Hammer.—See "Hammer."

Ball Bearing.—A support designed specially for lessening friction by the use of balls partly contained in sockets, each ball being loose and turning with the object supported.

Ball Bearing Jack.—See "Jack."

Ball Check Valve.—See "Valve."

Ball Cock.—A stop-cock operated by a hollow sphere or ball of metal attached to the end of a lever which turns the stop cock of a water pipe and regulates the supply of water. Used in concrete work.

Balling Furnace.—See "Furnace."

Balling Tool.—See "Tool."

Ball Iron.—See "Iron."

Ball Joint.—See "Joint."

Ball Valve. See "Valve."

Baltimore Truss.—See "Truss."

Baluster.—A small pillar or column, supporting a rail, of various forms, used in balustrades or hand-rails. Also called "spindles," *q.v.*

Banded Granite.—See "Granite."

B. and O. Same as "Backing-out Punch." See "Punch."

Band Pulley.—See "Pulley."

Band Saw.—See "Saw."

Bank Discount.—See "Discount."

Bank Protection. The prevention of erosion of a bank of a stream by the use of riprap, mattresses, or other artificial means.

Bank Sill. See "Sill."

Bar.—Any piece of wood, metal, or solid material long in proportion to its cross-section. Also a barrier. An accumulation of silt, sand, or gravel, or a combination thereof which is deposited in streams and forms an obstruction therein.

Anchor Bar.—An eye-bar extending from the shoe of a span or tower into the concrete or masonry of the supporting pier or abutment for the purpose of holding down the span that rests thereon in case that it be subjected to uplift.

Arbitration Test Bar.—A form of small test bar used for determining the quality of material going into a casting.

Boring Bar.—A machine tool consisting of a special bar with cutters attached, used in a lathe or boring machine.

Bucking Bar.—The bar on a ring dolly which bears against a rivet, so as to hold the head during driving.

Capstan Bar.—See "Capstan."

Chisel Bar.—A heavy hand bar with a chisel edge on one end.

Claw Bar.—A hand bar with a bent, claw-shaped point for drawing spikes from railway ties or sleepers.

Bar.

Connecting Bar.—A bar which joins two parts or two members.

Corrugated Bar.—A type of deformed bar used as reinforcement in concrete. The deformations consist of a series of ridges transverse to the axis of the bar, their function being to engage the salient portions of the aggregate.

Crow Bar.—A hand bar of steel with a slightly-bent, wedge-shaped end, which is sometimes forked. Used as a pry or lever.

Deformed bar.—A reinforcing bar rolled with projections on its surface to ensure a better bond in the concrete in which it is placed.

Dolly Bar.—A riveter's tool or bar, used to hold the head of the rivet against the metal and act as an anvil while the other head is being made by a hammer.

Extension Bar.—A bar riveted to the end of a strut-channel, and projecting beyond it, to permit the passage of a pin.

Eye-bar.—See "Eye-bar."

Guide Bar.—One of the guides upon which the cross-head of an engine slides. Any bar used as a guide to a moving piece.

Holding-on Bar.—A lever which is used to hold one head of a rivet against the impact of the hammer while the other head is being formed with a snap.

Kahn Bar.—A type of reinforcing bar. Its special feature is the sheared prongs which project from the main stem at an angle of forty-five degrees, approximately, in order to take care of the shear in the beam.

Lacing Bar.—Any bar used in a system of "Lacing," *q.v.*

Latch Bar.—The sliding bar in the locking mechanism of a draw span.

Lattice Bar.—Any bar used in "Latticing," *q.v.*

Lock Bar.—Sheet piling which is locked together, and which can be pulled after being used for forms.

Pick-up Bar.—A hand bar with two prongs riveted on one end; used, after the concrete is poured, for picking up and shaking the reinforcing steel lying on the bottom of the form.

Merchants Bar.—Wrought-iron bars in their finished form ready for sale.

Muck Bar.—The bar made by the first rolling of the bloom.

Natural Bar.—A bar of sand or gravel formed in a river bed by the usual physical process of precipitation.

Pinch Bar.—A form of crowbar with a short projection like a heel, or fulcrum, at the end; used to pry forward heavy objects.

Puddle Bar.—Same as "Muck Bar," *q.v.*

Reinforcing Bar.—A bar or rod placed in concrete constructions to increase their resistance, especially to bending and shear.

Sand Bar.—A deposit of sand in a river.

Shackle Bar.—A bar used for pulling driftwood from a stream.

Shaker Bar.—Same as "Pick-up Bar," *q.v.*

Splice Bar.—The short bar used for making the joints in railroad rails.

Spudding Bar.—A bar used to drill a hole through the overlying earth to rock, in order to make an entrance for the rock drill.

Switch Bar.—A bar which connects the movable rails of a switch.

Tamping Bar.—A bar used for tamping material.

Tension Bar.—Any bar subjected to tension.

Test Bar.—A sample bar used in testing the strength of a material.

Tie Bar.—A bar connecting two parts of a structure. Also a bar used for connecting the two rails of a track.

Z-Bar.—A rolled steel shape having a cross-section resembling the letter "Z" and all angles right angles.

Barb Bolt.—See "Bolt."

Bar Buster.—See "Buster."

Bar Cutter.—See "Cutter."

Bar Dolly.—See "Dolly."

Barge.—A square-ended, flat-bottomed boat having capacity to carry bulky materials such as coal and rock. Used for erecting spans by flotation.

Machinery Barge.—A barge which carries machinery; used in construction work.

Barge Spike.—See "Spike."

Bar Iron.—See "Iron."

Bark.—The outside covering of trees. To remove the bark from a tree, log, or pile. To scrape.

Barn-siding.—Planks that are used to cover the outside of barns, sheds, etc. Generally boards from $^{13}/_{16}$ inch to 1 inch thick, and up to 12 inches wide.

Barometer.—An instrument for measuring the weight or pressure of the atmosphere.

Bartizan.—A small turret corbelled out at the angle of a wall or tower to form a look-out. Often used in masonry or concrete bridges over the piers and abutments to afford pedestrians a place of refuge or vantage point for sightseers.

Bascule.—A moving span that rotates in a vertical plane about an axis that may be either fixed or movable.

Rolling Bascule.—A bascule which retreats as it rises by having a cylindrical surface roll on a plane. In some types both surfaces are toothed.

Roller-bearing Bascule.—A type of bascule which has a fixed axis of rotation and which is supported on friction rollers to reduce the resistance to turning.

Trunnion Bascule.—A type of bascule which is supported by an axle or trunnions, about which it rotates without translation.

Bascule Bridge.—See "Bridge."

Bascule-leaf.—That portion of a bascule which actually revolves in a vertical plane.

Bascule Span.—See "Span."

Base.—That portion of any construction which rests on its natural support, such as the bottom of a pier or pedestal. It is generally enlarged as compared with the superimposed construction so as to reduce the intensity of the bearing pressure.

Wheel Base.—The space occupied by a group of wheels sustaining a load.

Base Casting.—See "Casting."

Base Line.—See "Line."

Base of Rail.—See "Rail."

Base Plate.—See "Plate."

Basic Open-hearth Furnace.—See "Furnace."

Basic Open-hearth Steel.—See "Steel."

Basic Pig.—See "Pig."

Basil.—The angle at the cutting edge of a tool or instrument.

Basing.—A finished projection around the bottom of a column located just above the ground level; similar to the baseboard of a room.

Basket Crib.—See "Crib."

Bastard File.—See "File."

Bastard Granite.—See "Granite."

Bat.—A broken brick.

Bat Bolt.—See "Bolt."

Bateau Bridge.—See "Bridge."

Bath-tray.—A tray, generally of zinc, used for washing blue prints in a water bath.

Batten.—A strip or scantling of wood. A bar nailed across a group of parallel boards to hold them together. To tie down or fasten securely.

Batten-door.—A door made of sheathing, secured by strips of boards, placed crossways, and attached with clinched nails.

Batten Plate.—See "Plate."

Batter.—To strike with repeated blows. An incline from the vertical; said of a wall having a face receding as it rises. To incline a face or line in masonry or any other construction.

Frost Batter.—A forward inclination of the back face near the top of a wall, the object being to allow the earth to lift upward under the action of frost, and thus prevent an additional horizontal pressure at the top of the wall.

Batter Brace.—See "Brace."

Battered Pier.—See "Pier."

Battered Pile.—See "Pile."

Battering Ram.—See "Ram."

Batter Pile.—See "Pile."

Batter Post.—Same as "Batter Brace," *q.v.*

Battery.—A generator of electricity by the action of chemicals.

Baulk.—Same as "Balk," *q.v.*

Bauschinger's Experiments.—See Johnson's "Materials of Construction," or Merriman's "Mechanics of Materials."

Bay.—The portion of a trestle between two columns. The English term for a panel of a truss.

Bead Joint.—See "Joint."

Beam.—A member the principal function of which is to carry a transverse load.

Bethlehem Beam.—A special rolled beam having a thin web and wide flanges made in the Gray mill of four rolls. Manufactured by the Bethlehem Steel Company.

Box Beam.—A hollow beam, generally rectangular in section, having its sides made of plates united by angle-irons.

Built Beam.—A beam made up of structural shapes, such as plates and angles, riveted together.

Cantilever Beam.—A beam supported at one end only.

Collar Beam.—A horizontal timber stretching from one to another of two rafters which meet at the top, and which are above the main tie-beam.

Continuous Beam.—A beam that rests on three or more supports.

Cross Beam.—A beam which runs transversely to the centre line of a structure.

Deck Beam.—A rolled shape having a "T" cross-section but with a slight enlargement at the lower end of the stem or web.

Flitch Beam.—A compound wooden beam strengthened with a "flitch plate," *q.v.*

Footing Beam.—The tie-beam of a roof.

Hammer Beam.—A short beam attached to the foot of a principal rafter to act in place of a tie-beam.

I-Beam.—A rolled structural shape having a cross-section resembling the letter "I."

Joggle Beam.—A built-up beam having a joggle, *q.v.*

Leading Beam.—A beam placed as a guide for other beams.

Needle Beam.—A cross-beam supporting a load, used in underpinning walls.

Rolled Beam.—A metal beam made by a rolling process.

Simple Beam.—A beam having its ends free and resting on two supports only.

T-Beam.—A reinforced concrete-beam or a rolled structural shape having a cross-section resembling the letter "T."

Tension Beam.—A beam subjected to tension as well as to cross-bending.

Tie Beam.—A timber that serves as a tie between walls.

Transverse Beam.—Any beam of a bridge that passes from one truss to an adjacent truss.

Trussed Beam.—A beam braced by one or more vertical posts supported by inclined rods attached to the ends of the beam.

Beam Compass.—See "Compass."

Beam Hanger.—See "Hanger."

Beam-hanger Nuts.—See "Nuts."

Beam-hanger Plate.—See "Plate."

Beam Span.—See "Span."

Beam-trussing Posts.—See "Post."

Beam-trussing Rods.—See "Rod."

Bearing.—The angular position of a line referred to a meridian. The support for a shaft, axle, or trunnion. The shoes for a span. The resistance to crushing as offered by a member. The pressure transferred from one member to another. The capacity of a pile to carry load. The support for a beam, pin, bolt, or rivet.

Allowable Bearing.—The maximum intensity of pressure on a support allowed by the specifications.

Ball Bearing.—See "Ball Bearing."

Centre Bearing.—A term applied to swing spans to indicate that the dead load support is near the axis of the pivot pier instead of near the periphery thereof.

Even Bearing.—A bearing in which the pressure is uniformly distributed.

Expansion Bearing.—A support at the end of a span where provision is made for the expansion and contraction of the structure.

Journal Bearing.—The immediate support of an axle or a shaft.

Oil Bearing.—A bearing having a reservoir for oil in its base and rings running loosely over the journal, or shaft, dipping into the oil, so that their rotation continuously carries the oil to the journal and thus provides constant lubrication.

Pin Bearing.—A type of end support for a girder or a truss in which a pin is used to transfer the load to the shoe.

Rim Bearing.—A term applied to swing spans to indicate that the dead load is supported by a circular girder near the periphery of the pivot pier instead of near its axis.

Rocker Bearing.—A bearing, or support, for solitary trestle bents or cantilever spans which permits of a slight rocking with the changing position of the live load and with variations of temperature.

Roller Bearing.—A shoe or plate resting on rollers which in turn rest on a base casting at the expansion end of the span.

Sand Bearing.—A bearing of confined sand used for the purpose of lowering the object that is temporarily supported. The lowering is effected by permitting the sand to escape. Also the support for the core in a sand mould for casting.

Shaft Bearing.—A support for a revolving shaft.

Sliding Bearing.—A bearing constructed so that one part slides on another.

Thrust Bearing.—A support for a shaft adapted to take up the end thrust therefrom.

Bearing Pile.—See "Pile."

Bearing Plate.—See "Plate."

Bearing Point.—The point of support for a load or a place where concentrated pressure is applied.

Bearing Pressure.—See "Pressure."

Bearing Stress.—See "Stress."

Beater.—A bridgeman's term for a maul.

Becket.—A short piece of rope with a knot at one end and a loop, or eye, at the other. A handle made of a rope sling. An iron U-strap fixed to a pulley block, so as to provide a loop for attaching a rope.

Becket Bend Knot.—Same as "Sheet Bend Knot." See "Knot."

Becket Block.—See "Block."

Becket Hitch.—A fisherman's knot. See "Knot."

Bed.—A surface or body of rock, earth, or shale which serves as a foundation. The foundation piece on which a machine rests. A layer of cement or mortar in which the stone is embedded. To place stone or brick in mortar. To embed. To place a thing on its bearing.

Bed.

Foundation Bed.—The earth or rock surface on which a construction rests.

Key Bed.—In machinery, a rectangular groove made to receive a key for the purpose of binding the parts that are in contact.

Natural Bed.—The bed of a stone as it lay in the quarry.

Bed Frame.—See "Frame."

Bed Joint.—See "Joint."

Bed Plate.—See "Plate."

Bed-rock.—The solid rock lying under loose detrital masses, such as sand or gravel.

Bed Stone.—See "Stone."

Beetle.—A heavy wooden mallet used to drive wedges, also to consolidate earth.

Belay.—To make fast around a belaying-pin, cleat, or cavel.

Belaying-pin.—A wooden or iron pin to which a rope is belayed or tied.

Belgian Tank Locomotive.—See "Locomotive."

Bell.—The large end of a pipe or tube turned out in the shape of a bell.

Bell and Hopper.—A charging device on top of a blast furnace.

Bell Crank.—See "Crank."

Bellows.—An apparatus or box with flexible leather sides so arranged by means of a valve that it may be opened and closed in succession, thereby producing a current of air.

Belt.—A course of stones or bricks projecting from a structure, generally lying in a horizontal plane. Sometimes called a "stone-ring." Also a flexible strip of leather, rubber, or any other material which passes around the periphery of wheels, drums, etc. for transmitting motion from one to the other.

Driving Belt.—A band, rope, strap, or belt which transmits motion from one machine to another, or from one part of the same machine to another part.

Belt Course.—See "Course."

Belted.—Driven by a belt.

Belting.—The material from which belts are made. Also a general term for a number of belts taken collectively.

Link Belting.—A belt for the transmission of power, composed of a series of detachable links.

Belt Saw.—Same as "Band Saw." See "Saw."

Bench.—A table upon which mechanics do their work; a ledge made on the edge of an earth cutting in order to strengthen it.

Bench Dog.—See "Dog."

Bench-mark.—A mark cut in a rock or located on some permanent object to record the elevation at that place in a line of levels.

Bench-table.—A low stone seat carried around a wall.

Bench Vise.—See "Vise."

Bend.—A band or clamp of metal used to strengthen a box or frame. The action of bending, or the state of being curved.

Bending Moment.—See "Moment."

Bending Slab.—See "Slab."

Bending Stress.—See "Stress."

Bending Test.—See "Test."

Bends.—A pneumatic caisson disease, due to the abnormal air pressure. It is a species of temporary paralysis.

Bent.—A condition of being curved or kinked. A supporting frame consisting of posts or piles with bracing, caps, and sills.

Cluster Bent.—A bent having a cluster of piles driven at the places of heavy load concentrations.

Column Bent.—A bent composed of columns and bracing in contra-distinction to "pile bent."

Bent.

Framed Bent.—A bent composed of framed timbers.

Pile Bent.—A bent having piles for supporting posts.

Rocker Bent.—A bent generally of steel, though sometimes of timber, hinged at either one or both ends so as to provide for the expansion and contraction of the span supported.

Solitary Bent.—A single bent of a trestle that is not attached to either adjacent bent except by the girders of the deck.

Timber Bent.—Same as "Framed Bent," *q.v.*

Trestle Bent.—In trestle construction, one of a series of bents carrying a deck.

Bent Club Dolly.—See "Dolly."

Bent-eye.—An eye on the end of a bar, the plane of which makes an angle with the direction of the bar. Formerly used in bridges, but now abandoned as unscientific.

Bent Linked Chain.—See "Chain."

Bent Loop.—See "Loop."

Berm or Berme.—The portion of the supporting soil of an embankment lying between the toe thereof and the side-ditch.

Berm Stakes.—See "Stakes."

Bessemer Furnace.—See "Furnace."

Bessemer Pig.—See "Pig."

Bessemer Process.—A process for making steel by the decarburization of crude pig iron by means of a finely divided air current blown through the metal when in a molten state. Named from its inventor Sir Henry Bessemer.

Bessemer Steel.—See "Steel."

Bethlehem Beam.—See "Beam."

Bethlehem Column.—See "Column."

Béton.—A mixture of lime, sand, and gravel forming a kind of concrete. Sometimes used as a synonym for concrete.

Béton-Coignet.—A mixture of Portland cement, siliceous hydraulic lime, and clean sand mixed together with fresh water. See "Cement." Named after its French inventor, a Monsier Coignet.

Bettle.—a heavy wooden rammer. A workmen's corruption of "Beetle."

Bevel.—The slope on the end of a piece; an instrument for drawing angles—used by mechanics. To slope or sharpen an edge.

Beveled-edge.—An edge that is made thin by bevelling.

Beveled Gear.—See "Gear."

Beveled Gear Jack.—See "Jack."

Beveled Joint.—See "Joint."

Beveled Tie.—See "Tie."

Beveled Washers.—See "Washers."

Beveled Wheel.—See "Wheel."

Bicalcic Silicate.—See "Silicate."

Bid.—To make a price on anything. A proposition, either verbal or written, for doing work.

Unbalanced Bid.—A bid in which some of the unit prices are abnormal, either too high or too low, or generally both.

Bight.—A loop of a rope in distinction from the ends; any bent part or turn of a rope between the ends.

Billet.—A small bloom; a short, chunky bar of iron or steel.

Bill of Material.—A list of the various portions of material for a construction, either proposed or completed, giving dimensions and weights or other quantitative measurements.

Bin.—A place for storing materials, such as cement, sand, or broken stone.

Cement Bin.—A bin, usually at the cement mills, in which cement is stored for aging.

Binder.—A substance that will hold, or will bind together, different materials or the numerous parts of the same material, such as bitumen. This term is generally used in reference to pavements.

Binder Course.—See "Course."

Binding Joists.—See "Joists."

Binocular.—A double telescope for the use of both eyes.

Bird's-mouth Joint.—See "Joint."

Bit.—A tool for boring into wood or metal.

Bite of a Line.—The enclosed space between the parts of a line which passes through a pulley-block or a hook.

Bitt.—A strong post of wood or iron to which cables are made fast.

Bitumen.—Any native mixture of hydro-carbons oxygenated, as naphtha, and especially asphalt.

Bituminous Cement.—See "Cement."

Bituminous Concrete.—See "Concrete.

Black Lead.—See "Lead."

Black-lead Graphite.—Same as "Graphite," *q.v.*

Blacksmith's Forge.—See "Forge."

Blackwall Hitch Knot.—See "Knot."

Blank Bolt.—See "Bolt."

Blast Furnace.—See "Furnace."

Blast Pipe.—See "Pipe."

Bled Ingot.—See "Ingot."

Blind Arch.—See "Arch."

Blind Axle.—See "Axle."

Blind Header.—See "Header."

Blister.—To raise filmy vesicles on a surface by heat. A small raised portion of a metal surface with a void beneath.

Blister Steel.—See "Steel."

Block.—Any obstruction or cause of obstruction; an obstacle. Any solid mass of matter usually with one or more plane faces; such as a block of wood, metal, stone, etc. A combination of a frame with one or more grooved pulleys, or sheaves, held therein; used in connection with ropes to multiply force. Also called "pulley-block." To obstruct. To support with blocks, as to block up.

Balance Blocks.—Small blocks used on counterweights of lift spans to make the final adjustment in counterbalancing the span.

Becket Block.—A hoisting block having a becket to which a rope may be attached.

Camber Blocks.—Blocks of wood or wedges of steel used during erection to give camber to a span, and so placed as to be easily removed when swinging it.

Cedar Block.—A paving block, usually round, made of cedar.

Chain Blocks.—See "Chain Blocks."

Chock-a-block.—The condition of a set of blocks and tackle when the blocks can go no closer together. Called also "block and block" and "two blocks."

Chock Block.—A device for stopping the motion of the traveling wheels of a portable machine.

Differential Block.—A double block having sheaves of different diameters.

Double Block.—A pulley block having two sheaves.

Fall Blocks.—Pulley-blocks used with ropes or "fall-lines."

Foot Block.—A heavy casting which supports the mast in a derrick, and permits of its turning.

Gate Block.—Same as "Snatch Block," *q.v.*

Gin Block.—A simple form of tackle block having a single wheel over which a rope runs.

Guide Block.—Same as "Guide Bar." See "Bar."

Block.

Hoisting Block.—The lower pulley block of the block and falls, carrying the hoisting hook.

Hook Block.—A pulley block fitted with a hook at one end.

Lead Blocks.—Blocks for guiding ropes or for holding them in a given position without impeding their motion. The blocks through which the lead lines run.

Link Block.—A block in a steam engine attached to a valve stem.

Pedestal Block.—Same as "Base Casting;" see "Casting." Also a stone block to support a column.

Pillow Block.—A type of journal bearing having a removable cap. Also called a plummer block.

Plummer Block.—Same as "Pillow Block," *q.v.*

Pulley Block.—A movable block or frame supporting and partially enclosing one or more grooved pulleys or sheaves.

Purchase Block.—A double-strapped pulley block having two grooves in the shell.

Quadruple Block.—A block containing four sheaves either arranged side by side or in tandem fashion.

Running Block.—A movable block in a system of tackles.

Saucer Block.—A cast iron or steel block dished, or saucer shaped, in which a capstan or the bottom of a boom rests and turns around.

Shoe Block.—A form of pulley block. Also same as "Base Casting," *q.v.*

Shoulder Block.—A sheave in a frame having a shoulder to prevent the rope through the block from becoming jammed.

Single Block.—A pulley block containing one sheave only.

Sister Block.—A block having two sheaves, arranged in tandem.

Snatch Block.—A pulley block with one side capable of being opened for the insertion of a rope. It is used principally to change the direction of a running line.

Standing Block.—A pulley block fixed to some permanent support.

Tail Block.—An accessory pulley block having a rope fastened around the shell to take the place of the usual becket.

Triple Block.—A block having a set of three sheaves.

Truss Block.—A bearing block of metal placed between the truss rod and the strut of a trussed beam.

Block and Block.—The condition of the two blocks in a tackle when drawn up close together. Also called "Two Blocks" and "Chock-a-block."

Block and Falls.—A set of pulley blocks with hemp ropes or steel cables roven through them; used for hoisting purposes or for exerting a strong pull. Also called "Block and Tackle."

Block and Tackle.—Same as "Block and Falls," *q.v.*

Block Brake.—See "Brake."

Blocking.—The set of blocks which is placed under anything to raise and support it.

Blocking Hammer.—See "Hammer."

Bloom.—A roughly prepared mass of iron or steel nearly square in section and comparatively short in proportion to its thickness.

Bloomated.—Made into blooms.

Blooming Rolls.—Rolls in which puddle balls of iron or steel are squeezed into blooms.

Blow.—That portion of the time occupied by a certain stage of a metallurgical process in which the blast is used. To explode. In caisson work the term "blow" refers to the letting of air out of the working chamber so that the caisson may drop.

Blow Gun.—See "Gun."

Blow-hole.—A defect in iron or steel caused by the escape of gas or air while solidifying.

Blowing of Mortar.—See "Mortar."

Blow-out.—The mechanism for blowing material through a pipe or tube. The bursting of forms, or shells, holding material, such as concrete. The sudden escape of air from a caisson.

Dry Blow-out.—A process for removing sand or mud from the working chamber of a pneumatic caisson by the pressure of air on the material piled around the mouth of the discharge pipe, no water being added nor sump used.

Wet Blow-out.—A process of blowing material from the working chamber of a caisson by wetting it, and placing it at the mouth of the discharge pipe.

Blow Pipe.—See "Pipe."

Blue Print.—See "Print."

Blue Printing.—A method of photo-printing by using paper sensitized with ferroprussiate of potash.

Blue Print Paper.—See "Paper."

Blue-short Iron.—See "Iron."

Blue-shortness.—A condition of brittleness in wrought iron caused by its having been worked at a blue heat.

Blunt File.—See "File."

Board-measure.—The standard measure for timber, the unit being a piece one foot square and one inch thick. Timber is sold at so much per thousand feet board measure usually written "per M.B.M."

Boasted Dressing.—See "Dressing."

Boasting.—A mason's process of dressing the surface of a stone with a broad chisel and mallet.

Boat Bridge.—Same as "Pontoon Bridge." See "Bridge."

Boat Hook.—See "Hook."

Boat Knot.—See "Knot."

Boat Ratchet.—See "Ratchet."

Boat Spike.—See "Spike."

Bogie.—A small truck, or carriage, running crosswise of a saw-mill carriage to shift the log at right angles to its length when on the main carriage.

Bog Iron.—See "Iron."

Boil.—To bubble up or be in a state of ebullition through the action of heat. A whirl or vortex in a stream.

Boiler.—A vessel or receptacle in which any liquid is boiled.

Locomotive Boiler.—A form of steam boiler in which the fire-box is connected by a number of flues with the smoke box under the chimney.

Boiler Plate.—See "Plate."

Boiler Steel.—See "Steel."

Boiling Test.—See "Test."

Bollman Truss.—See "Truss."

Bolster.—A perforated wooden block upon which sheet metal is placed to be punched. A sleeve-bearing through which a spindle passes. A bar placed across the middle of a car truck to support the body. In stone sawing, one of the loose wooden blocks against which the ends of the pole of the saw rests. One of the transverse pieces of an arch centering. A timber or thick iron plate placed between the end of a bridge and its seat on the abutment.

Corbel Bolsters.—Bolsters made in the form of corbels. Projecting bolsters.

Bolt.—A cylindrical jet, as that of water. A metallic pin or rod having a head at one end and a thread on the other for screwing up a nut. Used for holding members or parts of members together.

Anchor Bolt.—A round, steel bolt embedded in concrete or masonry to hold down machinery, castings, shoes, spans, engine beds, etc.

Assembling Bolt.—A threaded bolt for holding together temporarily the several parts of a structure during riveting.

Bolt.

Barb Bolt.—A bolt having jagged edges so as to prevent its being withdrawn from the object into which it is driven. Also called a rag bolt.

Bat Bolt.—A bolt barbed or jagged at the butt, or tang, to give it a firmer hold.

Blank Bolt.—A bolt having a fixed head, but no threads nor nuts.

Brohard Expansion Bolt.—A bolt with a screw attachment and a screwed collar over it. This bolt is used in concrete after hardening. A hole is driven, the collar inserted, and then the bolt is screwed in.

Clinch Bolt.—A bolt with one of its ends designed to be bent over to prevent withdrawal.

Construction Bolt.—A common steel bolt used temporarily during construction; such as a bolt to hold forms together.

Cotter Bolt.—Same as "Cotter Pin," *q.v.*

Countersunk Bolt.—A bolt having its head beveled and flattened, so that when put into place the said head will not project from the surface.

Drift Bolt.—A short rod or square bar to drive into holes bored in timber for attaching adjacent sticks to each other or to piles. The length generally varies from one foot to two feet. A drift bolt may or may not be provided with a head or with a sharpened end.

Expansion Bolt.—Any bolt similar to the "Brohard Expansion Bolt," *q.v.*

Eye Bolt.—A bolt having a loop or eye at one end in place of the customary flat head.

Fish Bolt.—A bolt for securing a fish joint.

Fitting-up Bolt.—An ordinary bolt used to hold steel members together while the same are being riveted.

Floor Bolt.—A bolt used in the construction of a floor.

Fox Bolt.—A masonry bolt having either a head or a thread and nut at one end and a split with inserted wedge at the other. After the bolt, with the wedge inserted in the split, is placed in the hole it is driven down so as to spread the end; then it is grouted in.

Grip of a Bolt.—The length of a threaded bolt measured from inside of the head to inside of the nut when the latter is screwed on far enough to provide full thread.

Hacked Bolt.—A bolt which has been notched with a hatchet to use as a fox bolt.

Hook Bolt.—A bolt having one end in the form of a hook.

Joint Bolt.—A bolt joining one timber to another in a "T" form.

Key Bolt.—Same as "Cotter Pin." See "Pin."

Lewis Bolt.—A wedge-shaped-ended bolt inserted like the shank of a lewis in a hole drilled in a stone and fastened therein by pouring melted lead into the unoccupied part of the hole. An eye-bolt similarly inserted and used like a lewis for lifting heaving stones. See "Lewis."

Lug Bolt.—A round bolt to which is welded a flat iron bar.

Machine Bolt.—A threaded bolt having a straight shank and a square or hexagonal shaped head.

Packing Bolt.—A bolt which holds together the several parts of a composite member.

Rag Bolt.—Same as "Barb Bolt," *q.v.*

Ring Bolt.—Same as "Eye Bolt," *q.v.*

Screw Bolt.—A bolt having a square head for turning with a wrench and a wood screw on the opposite end for entering wood. A form of lag screw.

Skinned Bolt.—A bolt from which the threads have been stripped.

Standing Bolt.—Same as "Stud Bolt," *q.v.*

Stay Bolt.—A threaded rod or bolt binding together opposite plates to enable them to sustain each other against opposing pressure, as the stay bolt in a boiler.

Stove Bolt.—A small bolt having a rounded head, notched for a screw driver, at one end and a square nut at the other.

Bolt.

Strap Bolt.—Same as "Lug Bolt," *q.v.*

Stringer Bolt.—A bolt used to connect parallel wooden stringers that are laid side by side, a washer or separator being placed between each pair of stringers thus connected in order to let the air circulate between them and prevent decay. Usually these stringers are bolted together for the purpose of forming one member, or a composite stringer.

Stud Bolt.—A bolt with a thread cut at each end in order to be screwed into a fixed part at one end, leaving the other end projecting so as to receive a nut.

Sway Bolt.—A bolt which fastens the sway bracing to other timbers.

Swedge Bolt.—A bolt having a thread and hexagonal nut at one end and elliptical recesses at the other, used by some railways instead of fox bolts.

Tap Bolt.—A bolt which is screwed into the material which it holds instead of being screwed by a nut. Also called a tap screw.

Through Bolt.—A bolt which passes from side to side of the members which it fastens.

Tie Bolt.—A round bolt with a square shank and lip for hooking ties to the flanges of stringers.

Timber Bolt.—Any bolt used in connecting timbers.

Toggle Bolt.—A bolt connecting the parts of a toggle.

Track Bolt.—A bolt used for connecting railway rails through splice bars. It has an elliptical shank and a hexagonal nut. Often a square head is used.

Turned Bolt.—A machine bolt, ordinarily with hexagonal head, turned down so that when put in place it has a driving fit.

U-Bolt.—A rod bent in the shape of the letter U with threads and nuts on the ends.

Bolt Eye.—See "Eye."

Bolt Head.—See "Head."

Bonanza Tile.—See "Tile."

Bond.—Anything that binds, fastens, or holds together pieces of material, as the connection of one stone to another. A certificate of ownership of a specified portion of a capital debt due by a government, a city, a railroad, or other corporation, to individual holders, and usually bearing a fixed rate of interest. Also an electrical connection, such as a bar of copper wire soldered to two track rails near their junction. Also the manner of laying bricks or masonry stones. A guarantee.

Chain Bond.—A bond formed by binding a chain, a bar, or a heavy scantling into masonry.

Cross Bond.—A masonry bond in which a course composed of stretchers, except at the ends where headers are used, is covered by a course in which headers alternate with stretchers.

English Bond.—Same as "Old English Bond," *q.v.*

Flemish Bond.—A bond consisting of a header alternating with a stretcher in each course, but so placed that the outer end of each header lies on the middle of a stretcher in the course below.

Header and Stretcher Bond.—A form of masonry bond consisting of headers and stretchers alternating in the same row.

Heart Bond.—A masonry bond in which two headers in opposite faces of a wall meet in the middle of the wall, and have another header to cover the joint between them.

Old English Bond.—A masonry bond formed by laying alternately entire courses of headers or stretchers. Sometimes, though, only one course of headers is laid for every two or three courses of stretchers.

Random Bond.—A bond in which the stones or bricks are not laid in regular courses at all.

Bond.

Reticulated Bond.—A form of masonry bond in which the stones are square and are laid lozengewise, so that the joints resemble the meshes of a net.

Row Lock Bond.—A bond in an arch of concentric rings, formed by laying the bricks in each ring as stretchers leaving only the mortar to unite the several rings.

Bond Resistance.—See "Resistance."

Bond Stress.—See "Stress."

Boning.—A method used by carpenters and masons to determine whether a surface is in or out of wind. It consists in placing two similar straight edges on the surface, parallel to each other, and sighting over their upper edges to see if they coincide. If they do not, the surface is in wind.

Bonnet.—A cap over the end of a pipe. A cast-iron plate bolted down as a covering over an opening.

Boom.—A long beam or spar projecting from near the foot of a derrick, and sustaining the load that is raised from its outer end. In England the term is used as a synonym for a chord of a truss.

Chicago Boom.—An erector's hoisting apparatus, consisting of a timber or steel boom, without a mast, having a goose-neck casting on the lower end working in a saucer block on a temporary sill, and held in position by blocks and tackle attached to other parts of the structure.

Derrick Boom.—The long member in a derrick which supports the load at its outer end.

Boom Brace.—A tackle extending from the end of the boom to the top of the mast in a derrick. The trussing placed below or at the sides of the boom to strengthen it.

Boom Guy.—A line, cable, or adjustable rod fastened to the middle of a derrick boom and extending to the bull-wheel to which it is attached so as to act as a brace.

Boom Iron.—A circular iron ring on the end of a mast of a derrick.

Boom-out.—The position of the boom at its greatest reach.

Boom-seat.—The place in a derrick where the boom and the mast meet and rest on the sill.

Boom Tackle.—See "Tackle."

Bore.—To make a hole in any material by cutting away a part of it. To drill. The calibre, or internal diameter, of a hole, tube, or pipe.

Boring.—Any hole that has been bored, such as a boring for a pier foundation.

Core Boring.—A boring made by a core-drill by means of which samples of the material passed through, in the shape of a cylinder or core, are brought to the surface for inspection.

Wash Boring.—A boring made by a churn drill by means of which samples of the material penetrated, in granular form, are washed to the surface by a flow of water.

Boring Bar.—See "Bar."

Boring Casing.—See "Casing."

Boring Machine.—A machine used for boring holes.

Chord Boring Machine.—A boring machine used in bridge shops for boring pin-holes in chords.

Wood Boring Machine.—An apparatus, generally run by air, for boring holes in timbers.

Boring Mill.—See "Mill."

Borrow-pit.—An excavation made by the removal of material, specially for use in filling or in building an embankment.

Bosh.—A rough sketch, an outline, or a figure. A trough in which bloomery tools are cooled.

Boss.—The enlarged part of a shaft on which a wheel is keyed. A wooden vessel used by plasterers for holding mortar. A foreman or sub-foreman. One who directs work.

Boston Rod.—See "Rod."
Bottom Chord.—See "Chord."
Bottom Lateral Bracing.—See "Bracing."
Bottom Laterals.—Same as "Lower Laterals." See "Laterals."
Bow.—An arch of masonry, as in the gateway of a bridge. A flexible strip which can be bent to any desired curve, or an arcograph used in drafting.
Bowline and a Bight.—A knot forming a loop made with a bowline on a bight of a rope.
Bowline Knot.—See "Knot."
Bowstring Girder.—See "Girder."
Bowstring Truss.—See "Truss."
Box.—A cap that covers the top of a pump. A one-piece bearing, or support, for a shaft or journal. A casing about a valve. To form into a box or the shape of a box.
Coupling Box.—The box or ring of metal connecting the contiguous ends of two lengths of shafting.
Driving Box.—The journal box of a driving axle.
Journal Box.—A one-piece box or bearing for supporting a journal.
Mortar Box.—A box in which mortar is mixed.
Oil Box.—A box attached to certain types of bearings for holding waste saturated with oil.
Packing Box.—Same as "Stuffing Box," *q.v.*
Resistance Box.—A box containing resistance coils.
Roller Box.—An iron or steel box holding rollers for a bridge shoe.
Shafting Box.—A one-piece type of bearing for shafting, having a base and bolt holes for bolting to a support.
Stuffing Box.—A device for securing a steam-tight, air-tight, or water-tight joint about a movable rod. It consists of two parts or glands held together by bolts and so arranged that packing of some kind can be inserted between the glands and compressed, by means of tightening the nuts on the bolts, against the movable rod.
Tool Box.—A box for holding tools, generally provided with a handle in the centre for convenience in carrying it about.
Box Beam.—See "Beam."
Box Column.—See "Column."
Box Culvert.—See "Culvert."
Box-drain.—Same as "Box Culvert," *q.v.*
Box Girder.—See "Girder."
Box Strut.—See "Strut."
Brace.—Generally a strut supporting or fixing in position another member. Sometimes the term is applied to a tie used for such a purpose. The permanent part of a small tool used for boring.
Batter Brace.—The inclined end post of a truss, sometimes called the "Batter Post."
Boom Brace.—See "Boom."
Knee Brace.—Same as "Knee," *q.v.*
Tension Brace.—A brace which resists tension.
Braced.—Strengthened or well interlaced and linked together by bracing.
Braced Arch.—See "Arch."
Bracer.—A brace.
Bracing.—A system of braces, as in lateral systems.
Bottom Lateral Bracing.—Lateral bracing in the plane of the bottom chords of a truss.
Cross Bracing.—Same as "X Bracing," *q.v.*
Diagonal Bracing.—Bracing along diagonal lines.

Bracing.

Horizontal Bracing.—Bracing lying in a horizontal plane.

Horizontal Sway Bracing.—Sway bracing in a horizontal plane.

Ladder Bracing.—Bracing consisting of struts only.

Lateral Bracing.—A system of tension or compression members, or both, forming the web of a horizontal truss connecting the homologous chords of the opposite trusses of a span.

Longitudinal Bracing.—Bracing extending lengthwise of the structure, or parallel to its centre line.

Lower Lateral Bracing.—Same as "Bottom Lateral Bracing," *q.v.*

Overhead Bracing.—The upper lateral or the vertical sway bracing in through bridges. The term is usually applied to the vertical sway bracing, if there be any; if not, to the upper lateral bracing.

Portal Bracing.—The combination of struts and ties in the plane of the end posts at a portal which helps to transfer the wind pressure from the upper lateral system to the pier or abutment.

Side Bracing.—The bracing on the sides of falsework, of a timber trestle, or of a pony-truss bridge.

Stringer Bracing.—Diagonal bracing in the plane of the upper flanges of the stringers.

Sway Bracing.—Bracing transverse to the planes of the trusses; used to resist wind pressure and to prevent undue vibration.

Top Lateral Bracing.—Lateral bracing in the plane of the top chords.

Tower Bracing.—Bracing attached to the posts of towers.

Traction Bracing.—Same as "Train-thrust Bracing," *q.v.*

Train-thrust Bracing.—Bracing in the plane of the bottom laterals which transfers the thrust of a braked train from the stringers to the trusses.

Transverse Bracing.—Bracing which is perpendicular (or but slightly inclined) to the centre line of the structure.

Upper Lateral Bracing.—Same as "Top Lateral Bracing," *q.v.*

Vertical Bracing.—Wind bracing lying in a vertical plane, such as sway bracing

Wind Bracing.—Bracing which takes up the stresses induced by the wind.

X-Bracing.—Any system of bracing in which the diagonals intersect.

Bracing Frame.—A frame of steel or timber built in a manner to withstand distortion.

Bracket.—A knee, or knee brace, connecting a post or batter brace to an overhead strut.

Cantilever Bracket.—A bracket cantilevered out from another member.

Corner Bracket.—A steel bracket rigidly attached in a re-entrant corner of a structure.

Bracket Crab.—See "Crab."

Brad Awl.—See "Awl."

Bragger.—Same as "Corbel," *q.v.*

Brake.—A mechanical device for arresting or retarding the motion of a machine or vehicle by means of friction. To retard or stop motion by the application of a brake.

Air Brake.—A system of braking mechanism operated by compressed air.

Block Brake.—A brake used in retarding a moving part by pressure from a stationary block.

Friction Brake.—Same as "Prony Friction Brake," *q.v.*

Prony Friction Brake.—A brake used for measuring the effective power developed by an engine or turbine.

Solenoid Brake.—A combination of a solenoid and a movable iron core which is drawn into the helix when the electric current is flowing, thereby actuating the brake mechanism.

Braked-train.—A train in motion with the brakes set and the steam shut off.

Brake Horsepower.—See "Horsepower."

Brake Wheel.—See "Wheel."

Brass.—An important alloy consisting of copper and zinc. The detachable part of a bearing in immediate contact with the shaft or journal.

Journal Brass.—One of the pieces, usually of brass, which fits up against the journal in a journal box.

Braze.—To cover with brass. To solder with a special hard solder.

Breach.—A break, as a breach of contract, or a breach in an embankment.

Breaking Joint.—See "Joint."

Breaking Load.—See "Load."

Break in Grade.—See "Grade."

Breaking Stress.—See "Stress."

Break Joint.—See "Joint."

Breakwater.—Any structure, such as a mole, mound, wall, or sunken hulk, to break the force of waves and protect harbors.

Breast Plate.—A plate on a tool for the operator to press against, such as the breast plate on a hand drill.

Breast-summer.—A beam of wood, iron, or stone supporting a wall over a door or other opening; a kind of lintel. Called also Bressummer and Brestsummer.

Breast Wall.—See "Wall."

Brick.—A kind of artificial stone made of moistened and finely kneaded clay molded into rectangular blocks and hardened by burning in a kiln.

Carborundum Brick.—A brick of carborundum with serrated edges made in an electric furnace and used for smoothing or polishing.

Cement Brick.—A brick made out of cement and sand.

Clinker Brick.—Brick that forms the tops and sides of the arches in a brick-kiln and consequently is directly exposed to the fire. Being overburned and partially vitrified, clinker bricks are hard, brittle, and weak.

Compass Brick.—A brick having one edge shorter than the other. Used in lining shafts, etc.

Concave Brick.—A brick of special form with curved sides and radial ends used in making arches.

Dutch Brick.—A dirty-looking, brimstone brick used for paving yards and stables.

Facing Brick.—Brick suitable for the exterior of constructions where a neat finish is required.

Feather-edge Brick.—Same as "Compass Brick," *q.v.* Also called "voussoir brick."

Fire Brick.—A brick made of pure clay (or pure clay with a clean sand) to resist high temperatures.

Flemish Brick.—A species of hard yellow brick used for paving.

Hand Brick.—A scrubbing brick for hand operation.

Pale Brick.—Under-burned brick and, therefore, lighter in color than the fully-burned brick.

Paving Brick.—Any hard brick used in paving.

Pressed Brick.—A brick moulded from dry or semi-dry clay and pressed in a machine until it is very hard and smooth.

Sewer Brick.—Ordinary hard brick, smooth and regular in form, suitable for sewer construction.

Slop Brick.—An old-time brick made by depositing puddled clay in moulds and smoothing off the top with a wet stick run over the edges of the mould.

Vitrified Brick.—A glazed brick, made by fusing a silicious compound.

Bricklayer's Hammer.—See "Hammer."

Brick Masonry.—See "Masonry."

Brick Pier.—See "Pier."

Bridge.—A structure that spans a body of water, a valley, or a road and affords passage for pedestrians, or vehicles of all kinds, or any combination thereof.

Bridge.

Arch Bridge.—A curved structure which produces reactions inclined to the vertical.

Bascule Bridge.—A bridge having a span that opens by rotating in a vertical plane.

Bateau Bridge.—A floating bridge supported by boats or barges. A pontoon bridge.

Boat Bridge.—Same as "Bateau Bridge," *q.v.*

Cantilever Bridge.—A structure at least one portion of which acts as an anchorage for sustaining another portion which projects beyond the supporting pier.

Chain Bridge.—A suspension bridge in which chains are employed instead of the usual cables.

Combination Bridge.—A bridge constructed of timbers and steel or iron.

Combined Bridge.—A bridge which carries both railway and highway traffic.

Deck Bridge.—A bridge in which the passing loads are carried directly to the upper chords or to the upper portions of the posts.

Draw Bridge.—A bridge that may be drawn or turned to one side, or lifted up, either bodily or in sections, so as to permit boats to pass under or through it.

Fixed Bridge.—One that does not move except for expansion and contraction

Folding Bridge.—Same as a "Jack-knife Bridge," *q.v.*

Foot Bridge. —A bridge for foot passengers only.

Frame Bridge.—A bridge constructed of sticks of timber framed together.

Girder Bridge.—A bridge composed of plate or lattice girders.

Hanging Bridge.—Same as "Suspension Bridge," *q.v.*

High Bridge.—A bridge over navigable water having ample clearance beneath it to permit the passage of all vessel traffic without moving a span or any portion of one.

Highway Bridge.—A bridge that carries highway traffic only.

Hinge Lift Bridge.—A lift bridge which has its ends hinged together when down.

Hoist Bridge.—Same as "Lift Bridge," *q.v.*

I-Beam Bridge.—A small bridge consisting of a floor supported on I-beams.

Jack-knife Bridge.—A bridge in which the lifting arms fold on themselves at mid-length when in a raised position.

Lattice Bridge.—A bridge having riveted trusses with multiple intersection web systems.

Leaf Bridge.—A form of draw bridge in which the rising leaf, or leaves, swing vertically on hinges.

Leg Bridge.—A bridge resting on legs, formed by a downward extension of the end posts, instead of masonry abutments.

Lever Draw Bridge.—A draw bridge operated by means of a lever.

Lift Bridge.—A type of movable bridge which travels in a vertical plane, sometimes called a hoist bridge.

Lifting Bridge.—Same as "Lift Bridge," *q.v.*

Low Bridge.—A bridge over navigable water so low that some vessels cannot go beneath it without an opening passage being provided in the structure.

Motor Bridge.—A draw bridge operated by a motor, or a bridge which carries motor cars.

Movable Bridge.—A bridge with a "Movable Span." See "Span."

Pile Bridge.—A bridge consisting of pile bents and timber caps, stringers and bracing.

Pontoon Bridge.—A platform or roadway supported on pontoons or barges. A floating bridge.

Pull-back Draw Bridge.—A movable span which retreats longitudinally to allow the passage of vessels.

Railway Bridge.—A bridge which carries railway traffic.

Revolving Draw Bridge.—A draw bridge which turns in a horizontal plane.

Rolling Draw Bridge.—Same as "Pull-back Draw Bridge," *q.v.*

Rolling Lift Bridge.—A bascule bridge in which the moving arm rolls on a plane or upon friction rollers.

Bridge.

Rope Bridge.—A suspension bridge in which ropes are used for cables.

Skew Bridge.—A bridge in which the horizontal lines joining corresponding end-pins of the opposite trusses are oblique to the planes of the said trusses.

Stiffened Suspension Bridge.—A suspension bridge with stiffening trusses.

Stone Bridge.—A bridge built of stones laid in mortar.

Suspension Bridge.—A roadway suspended from chain or wire cables, usually hung between massive towers of masonry and securely attached to abutments. Also called a wire bridge.

Swing Bridge or **Swivel Bridge.**—A span that rotates about a vertical axis, so as to provide openings for the passage of vessels.

Through Bridge.—A bridge with overhead bracing and carrying its floor near the elevation of the bottom chords.

Trestle Bridge.—A bridge composed of bents or towers carrying the deck. May be of either timber or metal.

Truss Bridge.—A bridge made up of truss spans.

Tubular Arch Bridge.—A bridge in which the primary supporting members are arched tubes.

Tubular Bridge.—A plate-girder structure covered with metal construction on top and bottom, forming a boxed space through which the traffic passes.

Turning Bridge.—Same as "Swing Bridge," *q.v.*

Vertical Lift Bridge.—A bridge having a span that hoists vertically.

Wagon Bridge.—Same as "Highway Bridge," *q.v.*

Bridge Guard.—See "Guard."

Bridge-seat.—That part of the top of a bridge pier or abutment that receives directly the pedestals or shoes of the superstructure.

Bridge Tape.—See "Tape."

Bridge Truss.—See "Truss."

Bridging.—A piece of wood placed between and attached to two beams, or other pieces, in order to prevent them from approaching each other. It also means the spanning of any opening.

Bridging Joists.—See "Joists."

Bridging Stone.—See "Stone."

Briggs Logarithm.—See "Logarithm."

Briquette.—A standard shaped form or block made of cement or of mixed cement and sand; used for testing the tensile strength of the neat cement or of the mortar.

Cement Briquette.—A briquette made of cement and water for testing the tensile strength of the cement.

Neat Briquette.—Same as "Cement Briquette," *q.v.*

Sand Briquette.—A briquette made of sand and cement mortar.

Briquette Clips.—See "Clips."

Briquette Mould.—See "Mould."

Bristol-board.—A high quality of calendered cardboard used for fine drawings, printing, etc.

Brittle-zone.—In nickel steel testing, the stage between certain inferior and superior limits for percentage of nickel in the alloy where the metal is brittle, and both below and above which it is not.

Broach.—A boring bit or tapering tool for enlarging and smoothing holes. A reamer. Also a narrow-pointed chisel for dressing stone.

Broached Dressing.—See "Dressing."

Broad Axe.—See "Ax or Axe."

Brohard Expansion Bolt.—See "Bolt."

Broken Ashlar.—See "Ashlar."

Broken Ashlar Masonry.—See "Masonry."

Broken Axed.—A form of stone dressing. See "Dressing."

Broken Axed Dressing.—See "Dressing."

Broken Coursed Rubble.—See "Rubble."

Broken Line.—See "Line."

Broken Ranged Rubble.—See "Rubble."

Broken Range Masonry.—See "Masonry."

Broken Stone.—See "Stone."

Broken Stone Concrete.—See "Concrete."

Broken Top Chord.—See "Chord."

Bronze.—A reddish-brown alloy of copper and tin, sometimes containing small portions of other metals. Used in bridgework for journal or pivot bearings and for name-plates.

Bronze Steel.—See "Steel."

Brooming.—The breaking up under hammering of either the head or the point of a timber pile and reducing it to a fibrous mass.

Brushes.—The copper wires, plates, or carbon connections which make contact with the commutator on a dynamo or motor and serve to take off the electric current.

Bubble.—The vesicle of air or gas in the glass spirit-tube of a mechanic's or surveyor's level. A blister on a steel surface.

Buck.—To resist. To afford resistance. To press against a rivet-head with a dolly during driving.

Buck Brace. Same as "Cross Frame." See "Frame."

Bucker-up.—One who holds a dolly-bar on the head of a rivet while it is being driven.

Bucket.—A vessel for drawing up water or materials, as from a well. One of the scoops of a dredging machine. In general terms, any contrivance used for carrying materials in hoisting.

Clam Shell Bucket.—A dredging bucket composed of two curved leaves hinged about a point at their top and so arranged as to open or shut at the will of the operator.

Collapsing Bucket.—A bucket which can be made to drop its burden by folding or collapsing.

Grab Bucket.—Any dredge bucket that opens up and grabs its loading.

Orange Peel Bucket.—A dredging bucket composed of four curved and tapered pieces, hinged at their tops and so arranged that when closed they form a large cup for carrying materials. When opened to their full extent, four tooth-like prongs are presented for digging into the material. Loading is completed by closing up the four prongs or leaves.

Bucket Dredge.—See "Dredge."

Bucket Hole.—The hole or shaft in which a bucket travels.

Bucket Pump.—See "Pump."

Buckle.—To bend in a lateral direction by a longitudinal pressure.

Buckle Plate.—See "Plate."

Buckle Plate Floor.—See "Floor."

Buckle Plate Press.—See "Press."

Buckling Stress.—See "Stress."

Buffer.—Any apparatus for deadening the concussion between a moving body and another body against which it strikes.

Hydraulic Buffer.—An automatic device for checking recoil by means of water or other liquid forced under high pressure through a small aperture or apertures.

Buggy.—A small wagon used for transporting material such as rock. The carriage on which a traveling crane rests.

Timber Buggy.—A compact frame mounted on a single roller, used for transporting heavy sticks of timber.

Build.—The manner of construction. The form of anything. To frame, construct, or erect. The height of a cut masonry stone or its rise, used in contradistinction to its bed, as a "build joint" or a joint in a vertical plane.

Builder's Hoist.—See "Hoist."

Builder's Knot.—See "Knot."

Built Beam.—See "Beam."

Built Channel.—See "Channel."

Built Girder.—See "Girder."

Built Pile.—See "Pile."

Bulb Angle.—See "Angle."

Bulk.—The body of a substance. A painter's term applied to pigment to signify the total volume thereof plus the voids.

Bulkhead.—A partition built in a tunnel or conduit to prevent the passage of air, water, or mud, or in a form for concrete.

Bull-dog.—Calcined tap cinder from puddling furnaces.

Bulldozer.—A machine in which angles are bent in small circular arcs by pressure between two supports.

Bull Gang.—See "Gang."

Bull Press.—Same as "Gag Press." See "Press."

Bull Riveter.—See "Riveter."

Bull Wheel.—See "Wheel."

Bull Wheel Derrick.—See "Derrick."

Bull Wheel Pile Driver.—See "Pile Driver."

Bunker.—A bin used for storing purposes, such as the storing of coal or any other loose material.

Buoy.—A float fixed at a certain place to show the position of any object beneath the water's surface.

Buoyancy.—The upward pressure exerted upon a body by the fluid in which it is immersed. It is equal in amount to the weight of the water displaced.

Centre of Buoyancy.—The centre of gravity of the water displaced by any wholly or partially submerged body.

Buoyant Effort.—Same as "Buoyancy," *q.v.*

Buried Pier.—See "Pier."

Burlap.—A coarse, heavy cloth or mat made from jute, flax, hemp, or manila fibres.

Burning Steel.—See "Steel."

Burnish.—To polish by rubbing; applied chiefly to metals.

Burnt Steel.—See "Steel."

Burr.—A partially vitrified brick; a clinker. A protuberance or raised portion of an object. A nut with a screw-thread. The rough projecting edge of a drilled hole in steelwork.

Riveting Burr.—A washer upon which a rivet-head is swaged down.

Burr Truss.—See "Truss."

Bush.—A perforated box or tube of metal fitted into certain parts of machinery. To dress stone, or the manner of dressing it.

Bushel.—A unit of dry measure containing 2,150.42 cubic inches.

Bush Hammer.—See "Hammer."

Bush-Hammered Dressing.—See "Dressing."

Bushing.—Same as "Bush," *q.v.*

Buster.—A machine for cutting off the heads of rivets; also the edged tool which does the cutting.

Bar Buster.—A rivet cutter on the end of a bar.

Bust Hammer.—See "Hammer."

Butt.—To strike by thrusting; to join at the end. The thick, large, or blunt end of a timber or pile. The square end of a connecting rod.

Butt-end.—Same as "Butt," *q.v.*
Butt Joint.—See "Joint."
Butt Riveting.—See "Riveting."
Butt Splice.—See "Splice."
Butt Strap.—See "Strap."
Butt Weld.—See "Weld."
Button Head.—See "Head."
Button-headed Spike.—See "Spike."
Button Set.—See "Set."
Buttress.—A short cross-wall built against the main wall to increase its stability.
Flying Buttress.—A support in the form of a segment of an arch springing from a solid mass of masonry.
Butty Gang.—See "Gang."
Buzz Saw.—See "Saw."
By-pass.—An extra pipe passing around a valve or chamber to equalize pressure or to prevent a complete stoppage of the flow of the fluid.
By-product.—A secondary or additional product from any manufacturing process.
By-wash.—A channel cut to convey the surplus water from a reservoir or aqueduct, for the purpose of preventing overflow.

C

Cable.—A heavy rope, chain, or twisted wire rope. An aerial or underground conductor of electricity with insulating covering. The suspending portions of a suspension bridge.
Chain Cable.—A very heavy linked chain used in place of a steel wire cable in bridge-work.
Storm Cable.—An extra strong cable used to give additional strength or anchorage during severe wind-storms.
Suspender Cable.—A hanger cable in a suspension bridge for supporting the floor system.
Suspension Cable.—One of the cables forming the support of the floor of a suspension bridge.
Wire Cable.—A cable of heavy wire, or of numerous small wires twisted together.
Cable Clamp.—See "Clamp."
Cable Clip.—See "Clip."
Cable Hoist.—See "Hoist."
Cable Splice.—See "Splice."
Cable-way.—An underground passage carrying a cable or cables.
Cage.—A framework to confine a ball valve within a certain range of motion. A wire guard placed in front of a suction opening to allow liquids to enter, but to prevent the passage of solids of objectionable size. A skeleton framework of any kind surrounding any object.
Caisson.—A sunken panel in a coffered ceiling. A watertight box or casing used in founding and building structures in water too deep for cofferdams.
Open Caisson.—A crib and cofferdam open to the air and sunk by dredging within the crib.
Pneumatic Caisson.—A bottomless box or caisson, surmounted by a crib or shaft, into which air is pumped so as to drive out the water and thus permit workmen to enter for the purpose of excavating the bottom and sinking the mass to the required depth.
Caisson-disease.—Same as "Bends," *q.v.*
Calculated Horsepower.—Same as "Commercial Horsepower." See "Horsepower."
Calculation Paper.—See "Paper."

Caliber.—The inner diameter or bore of any tube.

Caliper.—An instrument, consisting of two adjustable moving parts, which is used to measure the outside or inside diameter of a cylindrical body.

Inside Caliper.—A caliper for measuring any inside diameter.

Micrometer Caliper.—A caliper having a micrometer screw.

Outside Caliper.—A caliper for measuring the outside diameter of a cylinder or tube.

Vernier Caliper.—A steel caliper with a vernier attachment which reads to thousandths of an inch.

Caliper Compass.—A caliper made similar to a drawing compass or dividers with curved legs for measuring inside and outside diameter.

Caliper Gauge.—A tool or standard for measuring with great accuracy.

Caliper Rule.—An outside caliper formed by a rule having a graduated slide at one end.

Caliper Square.—A rule carrying two cross-heads, one of which is adjusted slightly by a nut, the other being movable along the rule.

Calk, or Caulk.—To drive oakum or similar substances into seams of boxes, boats, barges, caissons, etc., in order to keep out the water. Also to copy a map by tracing.

Calked Rivet.—See "Rivet."

Calking-butt.—An open-end joint between planks in the side of a timber box or caisson.

Calking-iron.—A dull chisel for calking cofferdams and caissons.

Calking Mallet.—See "Mallet."

Calking Metal.—See "Metal."

Calking Nail.—See "Nail."

Calking Tool.—See "Tool."

Calyx Core Drill.—See "Drill."

Cam.—An eccentric; a piece fixed upon a revolving shaft in such a manner as to produce a reciprocating motion in a member making contact with it. Also called a wiper.

Heart Cam.—A form of cam-wheel used for converting uniform rotary motion into uniform reciprocating motion.

Camb.—Same as "Cam," *q.v.*

Camber.—The upward curvature of a span above its nominal position.

Camber Blocks.—See "Blocks."

Cambering Machine.—A machine used for bending beams to a curve in a vertical plane.

Camber Jack.—See "Jack."

Camber-slip.—A slightly curved guide and support of wood used as centering in laying straight arches of brick.

Camel-back Top Chord.—See "Chord."

Camel-back Truss.—See "Truss."

Cam Shaft.—See "Shaft."

Canal.—An artificial waterway for navigation. A duct.

Cancellation.—A system or arrangement of the web members in a truss.

Double Cancellation.—The arrangement of the web members of a truss having two complete systems of diagonals.

Multiple Cancellation.—The arrangement of the web members of a truss having more than two complete systems of diagonals.

Single Cancellation.—The arrangement of the web members of a truss having only one complete system of diagonals.

Triple Cancellation.—The arrangement of the web members of a truss having three separate systems of diagonals.

Candle-power.—The standard unit of luminous intensity equal to that given by the burning of a standard spermaceti candle at the rate of one hundred and twenty grains per hour.

Candle-wicking.—Wicks for candles; used sometimes for calking purposes.

Cant.—To turn over anything. The hook on a cant-hook for rolling timbers. To set at an angle; to tilt from a horizontal line.

Cant Dog.—Same as "Cant Hook." See "Hook."

Cant Hook.—See "Hook."

Cantilever.—A bracket of stone, metal, or wood projecting from a supported beam or wall. Also see Cantilever Bridge, under "Bridges."

Deck Cantilever.—A cantilever bridge in which the traffic is borne by a floor system supported by the top chords or the upper portion of the posts.

Through Cantilever.—A cantilever bridge in which the traffic passes between the trusses, in contra-distinction to a deck cantilever where it passes above the top chords.

Cantilever-arch Truss.—See "Truss."

Cantilever-arm.—The projecting arm in a cantilever bridge.

Cantilever Beam.—See "Beam."

Cantilever Bracket.—See "Bracket."

Cantilever Bridge.—See "Bridge."

Cantilever Crane.—See "Crane."

Cantilever Truss.—See "Truss."

Canvas Hose.—See "Hose."

Cap.—A covering of metal or of tarred canvas at the end of a rope to prevent fraying. The upper part of a journal box. The terminal section of a pipe having a plug at the end. A horizontal timber beam resting on and joining the heads of a row of piles or timbers. The top of a column. The part connecting a pump-rod with the working beam. Also a container for an explosive used in blasting. To cap or to cover.

Double Cap.—A cap set vertically on the top of another.

False Cap.—A cap on a column below the true cap. Also a construction to make an intermediate portion of a structure look like the top.

Falsework Cap.—Any cap used in falsework.

Hand-rail Cap.—The upper horizontal member or members of a hand-rail.

Pedestal Cap.—A block of stone or concrete placed on top of a footing to carry a loaded column.

Percussion Cap.—A small copper cap, or cup, containing fulminating powder which explodes when struck a sharp blow.

Pile Cap.—An iron casting shaped to fit over the head of a pile, and having a conical recess on top to carry a tough wooden block which receives the blows of the hammer. Jaws are provided on the sides of the cap to engage the leads. The function of the cap is to distribute the blow of the hammer and to prevent the brooming of the pile head. Also a timber cap across a row of piles.

Trestle Cap.—The upper horizontal beam in the timber framing supporting the deck of a trestle bridge.

Cape Chisel.—See "Chisel."

Capital.—The upper part of a column, pilaster, or pier. The money value set on the property or assets involved in a business enterprise.

Capitalized Cost.—See "Cost."

Capitalized Value.—Same as "Present Worth," *q.v.*

Cap Piece.—A rectangular timber covering the top of a row of squared timber posts.

Capping.—A general term for a series of caps in a structure. Putting a timber cap on a row of piles.

Cap Plate.—See "Plate."

Cap Screw.—See "Screw."

Cap Sill.—See "Sill."

Capstan.—An apparatus working on the principle of the wheel and axle, used for raising weights or applying power.

Barrel of a Capstan.—That part of a capstan around which the rope or cable is wound.

Chinese Capstan.—A differential windlass with its axis vertical, used for hoisting or hauling.

Differential Capstan.—A capstan operated by differential gears.

Pawls of a Capstan.—The stops on the bottom of a capstan to prevent backward motion.

Power Capstan.—A capstan in which cog-wheels are used to multiply the force and reduce the speed.

Capstan Bar.—One of the levers by which a capstan is turned.

Capstan Head.—See "Head."

Capstone.—The uppermost or finishing stone of a masonry structure.

Car.—A conveyance or receptacle running upon rails.

Derrick Car.—A railroad car upon which a derrick is mounted.

Dump Car.—A truck car having a body pivoted so that it can be turned partly over when emptying.

Erection Car.—A car specially fitted with a derrick and accessories, used for the erection of bridges.

Hand Car.—A small flat-car mounted on four wheels suitable for railway track and operated by handpower, used for carrying men and equipment for small repairs.

Locomotive Car.—A locomotive and railroad carriage combined in one.

Pneumatic Car.—A car running on rails and driven by compressed air motors.

Carbon Steel.—See "Steel."

Carborundum.—A combination of silica and carbon made in an electric furnace, used in place of emery as an abrasive material.

Carborundum Brick.—See "Brick."

Carpenter's Level.—See "Level."

Carpenter's Line.—See "Line."

Carriage.—Any part of a machine that carries another part. A drain. The timber frame which supports the steps of a wooden stair.

Wheel Carriage.—The frame or box holding the bearing wheels of a draw-span.

Carrick Bend Knot.—See "Knot."

Case-hardened Steel.—See "Steel."

Case-hardening.—Converting the outer surface of iron into steel by heating while in contact with charcoal.

Case Steel.—See "Steel."

Casing.—A wooden tunnel for the powder-hose in blasting. The outside pipe which is used in making borings. A covering.

Boring Casing.—A wrought-iron pipe from 2½ inches to 3 inches or more in diameter placed outside of the churn pipe, used in drilling test holes for pier foundations.

Timber Casing.—Timber sheathing used on the outside of caissons.

Cast.—To make a casting out of molten metal. A small brass funnel at the end of a mould for casting pipes.

Caster Wheel.—See "Wheel."

Cast Gear.—See "Gear."

Casting.—The act or process of founding. That which has been cast by pouring molten metal into a mould.

Base Casting.—A steel or iron casting upon which the bridge-shoe rests.

Certering Casting.—A casting used to bring a movable span to exact position when seated.

Chair Casting.—A casting used to support the end of a rail.

Chilled Castings.—Castings which are rapidly cooled during solidification.

Cast Iron.—See "Iron."

Malleable Cast "Iron."—See "Iron."

Cast-iron Pipe.—See "Pipe."

Cast Steel.—See "Steel."

Crucible Cast Steel.—See "Steel."

Catch.—Any mechanical contrivance used for stopping, checking, or preventing motion.

Catch-basin.—A reservoir placed at the outer end of a sewer connection to intercept the flow of water in a gutter.

Catch-drain.—Same as "Catch-water," *q.v.*

Catchment Area.—Same as "Drainage Area," *q.v.*

Catch-water.—A channel or drain running along sloping ground or pavement to catch and carry away the water.

Catch-work.—Same as "catch-water," *q.v.*

Catenary.—A curve formed by a flexible, inextensible cord or chain of uniform weight per unit of length, hung at two points and supporting its own weight alone.

Inverted Catenary.—A curve formed by reversing the position of an ordinary catenary so as to make it convex upward.

Transformed Catenary.—A curve formed by an increasing or decreasing of all the ordinates of a common catenary according to a given ratio.

Catenary Arch.—See "Arch."

Cat's-paw Knot.—See "Knot."

Cattle Guard.—See "Guard."

Causeway.—A raised footway or road.

Caustic Lime.—See "Lime."

Cedar Block.—See "Block."

Cell.—A unit of an electric battery consisting of two plates of different substances, usually zinc and carbon, immersed in an exciting liquid held in a jar, so as to set up an electric current.

Cement.—Any composition which at one temperature or one degree of moisture is plastic, and at another condition of temperature or moisture is tenacious. A mortar which hardens. To unite by cement.

Activity of Cement.—The time required for a cement to pass from its initial set to its final or hard set as determined by the Vicat Needle.

Bituminous Cement.—A cement or mastic in which bitumen, usually in the form of asphalt, is the chief ingredient.

Boiling Test of Cement.—See "Boiling Test."

Dry Process in Cement Manufacture.—The process of making Portland cement by mixing the ingredients dry and then burning them into a clinker.

Final Set of Cement.—See "Set."

Grappiers Cement.—A cement made in France from particles which have escaped disintegration in the manufacture of hydraulic lime.

Hard Set of Cement.—Same as "Final Set." See "Set."

Hydraulic Cement.—A cement which sets or hardens under water. There are three common kinds: Portland, natural, and Pozzuolana.

Initial Set of Cement.—See "Set."

Laitance of Cement.—That portion of a hydraulic cement which escapes from concrete that is placed under water and which floats on the surface. It is injurious to concrete, and should be removed. Its formation in large quantities indicates a defect in the method of depositing the concrete.

Liatier Cement.—Same as "Slag Cement," *q.v.*

Natural Cement.—Formerly a pulverized stone which, without having heat applied, acquired the property of hardening under water. The term is now applied to a cement made from natural rock (containing the required constituents in approximately uniform proportions) by calcining and grinding.

Cement.

Neat Cement.—Pure cement without the addition of sand, gravel, or rock.

Parker's Cement.—A name used in England for natural, or Roman cement.

Portland Cement.—A cement obtained by finely pulverizing clinkers produced by burning to semi-fusion an intimate artificial mixture of finely ground calcareous and argillaceous materials, this mixture consisting approximately of three parts of lime carbonate to one part of silica, alumina, and iron oxide.

Pozzuolana Cement.—A true natural cement made from volcanic ash and slaked lime. The name is derived from Pozzuoli, Italy, where it was first made in large quantities. In this country blast-furnace slag is substituted for the volcanic ash and the product is called "Puzzolan Cement."

Quick-setting Cement.—A cement that sets between five minutes and thirty minutes after mixing.

Roman Cement.—A natural cement of about the same characteristics as the Rosendale, supposed to have been used by the early Romans.

Rosendale Cement.—A hydraulic, natural cement that is light, quick-setting, and has an ultimate tensile strength of about one-half that of Portland cement. It comes from Rosendale, N. Y. The term has been improperly applied as a synonym for natural cement.

Rust Cement.—Iron turnings treated with acid and used to bed metal plates. Not permissible in good engineering practice.

Sand Cement.—A mechanical mixture of Portland cement and sand ground together so as to produce a very fine powder. Its only *raison d'être* is cheapness, as it is not as strong as good Portland cement.

Silica Cement.—Same as "Sand Cement," *q.v.*

Slag Cement.—Same as "Pozzuolana Cement," *q.v.*

Slapped Cement.—Cement mortar thrown against a structure, as used in rough-casting a house.

Slow-setting Cement.—A cement that sets in from one to eight hours.

Soundness of Cement.—A term denoting freedom from expanding, contracting, cracking, or checking in setting of cement.

Wet Process.—A method in the manufacture of cement in which the ingredients are mixed together with an ample amount of water, then dried, burned into clinkers, and ground.

Cementation.—The process of converting wrought-iron into steel while heating it in contact with charcoal. The act of cementing; the act of uniting by adhesive substances.

Cement Bin.—See "Bin."

Cement Brick.—See "Brick."

Cement Briquette.—See "Briquette."

Cemented Steel.—See "Steel."

Cement Finish.—See "Finish."

Cement Floor.—See "Floor."

Cement Gun.—See "Gun."

Cementing Furnace.—See "Furnace."

Cement Kiln.—See "Kiln."

Cement Mill.—See "Mill."

Cement Mortar.—See "Mortar."

Cement Mould.—See "Mould."

Cement Needle.—See "Needle."

Cement Pile.—Same as "Concrete Pile." See "Pile."

Cement Stone.—See "Stone."

Cement Testing Machine.—An apparatus for testing the strength of cement—generally for determining the tensile strength, but occasionally for finding the resistance to compression.

Centering.—See "Arch Centre."

Centering Casting.—See "Casting."

Centre.—The middle or reference point of an object.

Meta-centre.—See "Meta-centre."

Centre Bearing.—See "Bearing."

Centre-bearing Draw.—See "Draw."

Centre-bearing Turntable.—See "Turntable."

Centre Drill.—See "Drill."

Centre Line.—See "Line."

Centre of Buoyancy.—See "Buoyancy."

Centre of Displacement.—Same as "Centre of Buoyancy," *q.v.*

Centre of Gravity.—See "Gravity."

Centre of Gyration.—See "Gyration."

Centre of Inertia.—See "Inertia."

Centre of Magnitude.—That point in a body which is equally distant from all the similar external parts of it.

Centre of Mass.—See "Mass."

Centre of Moments.—See "Moments."

Centre of Motion.—Same as "Centre of Rotation," *q.v.*

Centre of Percussion.—See "Percussion."

Centre of Perspective.—See "Perspective."

Centre of Pressure.—See "Pressure."

Centre of Resistance.—See "Resistance.

Centre of Rotation.—See "Rotation."

Centre of Stress.—See "Stress."

Centre of Symmetry.—See "Symmetry."

Centre Pin.—See "Pin."

Centre Punch.—See "Punch."

Centre Valve.—See "Valve."

Centrifugal Force.—See "Force."

Centrifugal Load.—See "Load."

Centrifugal Pump.—See "Pump.'

Centrifugal Stress.—See "Stress.

Centripetal Force.—See "Force."

Centripetal Stress.—See "Stress."

Centroid.—The centre of mass, or centre of gravity. The point of application of the resultant of a system of stresses or forces.

Chain.—A connected series of links of metal serving the purpose of a band, cord, rope, cable, or measuring line. To tie or fasten with a chain.

Bent-linked Chain.—A coil chain in which the links are bit or bent.

Coil Chain.—A straight-linked chain, in which the links are in the shape of two letters U joined at their tops.

Curb Chain.—Any chain used as a check upon the motion of any moving piece or apparatus.

Endless Chain.—Any chain in the form of a loop without an end.

Hog Chain.—A chain cable or rod stretched over the straining posts in a Hog-chain Truss. See "Truss." Same as the rod used for trussing a beam.

Hook and Ring Chain.—A chain with a hook at one end and a ring at the other. Called also a "Sling Chain."

Hook Chain.—A chain having a hook on one end or one at each end.

Jack Chain.—A small chain each link of which is formed of a single piece of wire bent into two loops resembling the figure eight.

Jet Chain.—The chain which picks up a pipe that is used for the purpose of jetting.

Kibble Chain.—The chain which draws up the kibble or bucket from the hole.

Chain.

Link Chain.—A chain made of links.

Machine Chain.—A chain with twisted links that form a fairly flat surface.

Ring Chain.—A chain having rings at the end.

Roller and Thimble Chain.—A chain in which the links are connected by means of rollers and thimbles.

Sling Chain.—Same as "Hook and Ring Chain," *q.v.*

Stayed Link Chain.—A coil chain in which all the links are cross-braced. Called also a "Stud Link Chain."

Stud Link Chain.—Same as "Stayed Link Chain," *q.v.*

Wheel Chain.—A chain constructed so as to run over a chain wheel.

Chain Bearer.—That one of the staff in a survey party who carries and handles an engineer's or surveyor's chain or tape. The chainman.

Chain Blocks.—An endless chain running over two differential pulleys. Used for hoisting.

Chain Bond.—See "Bond."

Chain Bridge.—See "Bridge."

Chain Cable.—See "Cable."

Chain Casting.—See "Casting."

Chain Coupling.—See "Coupling."

Chain Dog.—See "Dog."

Chain Drive.—A mechanism consisting of a chain or chains for transmitting power.

Chain Gear.—See "Gear."

Chain Hoist.—See "Hoist."

Chain Hook.—See "Hook."

Chain Knot with a Toggle.—See "Knot."

Chainman.—Same as "Chain Bearer," *q.v.*

Chain Pulley.—Same as "Chain Wheel," *q.v.*

Chain Pump.—See "Pump."

Chain Riveting.—See "Riveting."

Chain-smith.—One who makes chains.

Chain Tape.—See "Tape."

Chain Wheel.—See "Wheel."

Chalk Line.—See "Line."

Chamber.—The recess in an axle box designed to hold the lubricant. A compartment or an enclosed space, as the chamber in a caisson.

Air Chamber.—An enclosed space containing air. In bridge work it usually refers to the working chamber in a pneumatic caisson.

Air Working Chamber.—A chamber in a caisson into which compressed air is forced to expel the water so that laborers can work at excavating.

Working Chamber.—Same as "Air Working Chamber," *q.v.*

Chamfer.—To bevel or sharpen to a blunt edge.

Chamfered Joint.—See "Joint."

Channel.—The deepest part of a river, bay, or stream; usually that part available for navigation. The trough used to conduct molten metal from the furnace to the moulds. To form or cut a channel. A structural or rolled steel shape used in bridge building and in other steel constructions.

Built Channel.—A shape in the form of a channel fabricated from a plate and two angle irons.

Rolled Channel.—A channel which is rolled in one piece, in contradistinction to the built channel.

Channel Column.—See "Column."

Channeling.—Making a new channel. Grooving or cutting in quarrying stone. A system of channels or gutters.

Channeling-machine.—A machine for cutting grooves or channels when quarrying stone.
Channel Iron.—Same as "Rolled Channel," *q.v.*
Channel Span.—See "Span."
Channel Strut.—See "Strut."
Characteristic Curve.—See "Curve."
Charcoal Iron.—See "Iron."
Charcoal Steel.—See "Steel."
Charred Piles.—See "Pile."
Chats.—Tailings from mills in which zinc and lead ores are treated.
Check.—A small crack in wood due to seasoning, or in concrete or mortar due to drying.
Heart Check.—A check in the heart of a timber.
Check Nut.—See "Nut."
Check Valve.—See "Valve."
Check Washer.—See "Washer."
Chenoweth Pile.—See "Pile."
Chilled Casting.—See "Casting."
Chilled Iron.—See "Iron."
Chinese Anchor.—See "Anchor."
Chinese Capstan.—See "Capstan."
Chinese Windlass.—See "Windlass."
Chipping Hammer.—See "Hammer."
Chisel.—A hard tool consisting of a sharp-ended blade designed to cut under the impulse of a blow.
Cape Chisel.—A hand tool made from a short steel bar having one end flat and the other tapering to a blunt edge sharpened at an obtuse angle to prevent breaking. Used in connection with a hand hammer for chipping cast iron. It differs from a cold chisel in having a narrower blade with more stock behind it.
Cold Chisel.—A hand tool made from a short steel bar having a flat top and a tapering wedge-shaped end a trifle wider than the shank. Used for cutting metals while cold.
Framing Chisel.—A heavy carpenter's chisel, used in mortising timbers.
Heading Chisel.—A mortise chisel.
Hot Chisel.—A chisel used for cutting metals while hot.
Pitching Chisel.—A stone mason's chisel for making a well-defined edge to the face of a stone block.
Slogging Chisel.—A heavy chisel used for cutting off bolt heads.
Splitting Chisel.—A wedged-shaped chisel.
Tooth Chisel.—Same as "Pitching Chisel," *q.v.*
Chisel Bar.—See "Bar."
Chisel Draft.—See "Draft."
Chiseled Dressing.—See "Dressing."
Chock.—A block, a piece of wood, or other material specially prepared and generally wedge-shaped, used to prevent movement by insertion under wheels, etc. To secure by putting a chock into or under a moving object, or one that is likely to move.
Chock-a-block.—Jammed. Said of a tackle when the blocks are so close hauled as to prevent further motion.
Chock Block.—See "Block."
Chord.—That portion of a truss the main function of which is to resist bending on the span.
Bottom Chord.—The lower member of a truss, usually resisting tension.
Broken Top Chord.—A top chord in which each successive segment deviates or deflects from the line of its contiguous segment, at the panel point.

Chord.

Camel-back Top Chord.—A top chord that is broken or deflects at two or, at most, three points.

Curved Top-Chord.—A top chord that approximates to the form of a curve. Strictly speaking such a chord is "polygonal," as curving chords between panel points is not permissible.

Lower Chord.—Same as "Bottom Chord," *q.v.*

Parabolic Chord.—A chord of a truss in which the panel points lie on the arc of a parabola.

Polygonal Top Chord.—A top chord composed of panel length segments which form a polygon.

Top Chord.—The upper member of a truss, usually resisting compression.

Upper Chord.—Same as "Top Chord," *q.v.*

Windward Chord.—The chord of a span on the windward side (the side from which the wind comes).

Chord Bar.—See "Bar."

Chord Boring-machine.—See "Boring-machine."

Chord Head.—See "Head."

Chord Packing.—See "Packing."

Chord Pin.—See "Pin."

Chord Pitch.—See "Pitch."

Chord Splice.—See "Splice."

Chord Stress.—See "Stress."

Chord Stringer.—See "Stringer."

Chrome Steel.—See "Steel."

Chuck.—A device attached to a revolving shaft or mandrel of a lathe for holding the object to be turned.

Drill Chuck.—A type of chuck which holds a drill.

Churn Drill.—See "Drill."

Chute.—An inclined trough or pipe along which substances are slid from a higher to a lower level. Also spelled "Shoot."

Cincture.—A ring, list, or fillet at the ends of a column serving to separate the shaft from the capital or the base.

Cinder.—Slag, especially that produced from making pig iron in blast furnaces. Ordinarily the residue of burnt coal, being the impurities thereof fused together to form lumps.

Puddle Cinder.—Cinder removed from the molten metal after the process of oxidizing the impurities has been completed.

Cinder Concrete.—See "Concrete."

Cinder Pig.—See "Pig."

Cinder Pocket.—See "Pocket."

Cinematics.—Same as "Kinematics," *q.v.*

Circle.—A graduated plate on a transit.

Circuit.—The arrangement by which an electrical current is conducted between the two poles of a generator or battery.

Circuit-breaker.—A device for automatically opening an electric circuit.

Circular Arch.—See "Arch."

Circular File.—See "File."

Circular Girder.—See "Girder."

Circular Pitch.—See "Pitch."

Circular Saw.—See "Saw."

Clack Valve.—See "Valve."

Clamp.—An instrument or tool consisting of two movable parts that can be drawn together by a screw or other suitable mechanism, used to fasten two objects together by pressure. One of a pair of movable cheeks on a vise. To fasten by pressure

Clamp.

Cable Clamp.—A clamp consisting of a U bolt, saddle, and two nuts, used on cables.

Fitting-up Clamp.—An ordinary screw clamp, used for fitting up instead of bolts.

Pipe Clamp.—A vise for holding pipes.

Rail Clamp.—A wedge used for tightening a rail in a rail chair.

Rope Clamp.—A device consisting of a pair of clamping jaws carrying a ring and hook used for securing or attaching the end of a rope to some object.

Screw Clamp.—A clamping device operated by a screw.

Clamp Drill.—See "Drill."

Clamp Iron.—Same as "Clamp," *q.v.*

Clamp Screw.—A clamp operated by a thumb-screw.

Clam-shell Bucket.—See "Bucket."

Clam-shell Dredge.—See "Dredge."

Clap-boards.—Short, thin boards, shingle shaped, and used instead of shingles.

Clapper Valve.—See "Valve."

Classification.—The distribution into sets, sorts, or ranks.

Classify.—To arrange in classes, sorts, or ranks according to some method founded on common characteristics in the objects so arranged.

Claw.—A split provided at the end of a bar or a hammer for taking hold of the heads of nails, spikes, or bolts so as to withdraw them from wood.

Clawback.—A balk or a beam, used in making floating bridges.

Claw Bar.—See "Bar."

Claw Coupling.—See "Coupling."

Claw Hammer.—See "Hammer."

Claw Wrench.—See "Wrench."

Clay-daubed.—Cracks filled with clay, as is sometimes done in forms for concrete.

Clay Puddle.—See "Puddle."

Clearance.—The space allowed for the passage of any vehicle or craft through or near a construction. The additional space allowed for the fitting together of members over that nominally required, in order to provide for slight irregularities of workmanship or materials.

Horizontal Clearance or **Lateral Clearance.**—The horizontal space allowed for the passage of any vehicle or craft through or near a construction.

Vertical Clearance.—The vertical or overhead space allowed for the passage of any vehicle or craft, measured above the roadway or the water level.

Clearance Diagram.—See "Diagram."

Clearance Line.—See "Line."

Clear-headway.—The vertical distance from the upper surface of a floor to the lowest part of the overhead bracing. It is the measure of height of the tallest vehicle that could pass through the bridge. Also the vertical distance from the water surface or the ground to the lowest part of the superstructure.

Clear Roadway.—See "Roadway."

Clear Span.—See "Span."

Clear Waterway.—See "Waterway."

Cleat.—A piece of wood or iron with projecting prongs, used for belaying or winding ropes on so as to make them fast.

Cleave.—To part or divide by force. To rend asunder, as to cleave wood or rock.

Cleveland Hammer.—See "Hammer."

Clevis.—A connecting iron bent into the form of a horseshoe, stirrup, or letter U. A link in a chain shaped like the letter U. An adjusting piece for bridge members of varying length.

Clevis Pin.—See "Pin."

Click.—Same as "Ratchet," *q.v.*

Clinch.—A hold-fast. To bend over a piece of projecting metal so as to make an attachment. To fasten firmly.

Clinch Bolt.—See "Bolt."

Clinker Brick.—See "Brick."

Clinton Wire Cloth.—A form of wire netting having nearly square meshes of large size with the longitudinal wires heavier than the transverse ones, used for reinforcing concrete.

Clip.—A fastening. The hinged yoke on top of the Y's in a spirit-level.

Angle Clip.—Same as "Clip Angle." See "Angle."

Briquette Clips.—The clips or jaws on a cement testing-machine which hold the briquette while being stressed.

Cable Clips.—A device for hanging an electric cable to a supporting cable, or for attaching anything to a cable.

Pulley Clip.—A clip attached to a pulley to prevent the wire rope (passing over it) from slipping.

Spring Clip.—A clip worked by a spring for holding sheets of paper.

Clip Pulley.—See "Pulley."

Closed Column.—See "Column."

Close-quartered Reamer.—See "Reamer."

Closing Line.—See "Line."

Closing Pile.—See "Pile."

Clove-hitch.—See "Knot."

Club Dolly.—See "Dolly."

Cluster Bent.—See "Bent."

Clutch.—A movable coupling or locking or unlocking contrivance used for transmitting motion.

Coil Friction Clutch.—A friction clutch composed of a coil wound on a chilled cast-iron drum.

Cone Clutch.—A clutch consisting of conical plug, sliding on its shaft and engaging a hollow drum shaped to receive the plug that rotates with the said shaft.

Friction Clutch.—A device for conveying motion from one line of shafting to another by the frictional resistance between plates in contact.

Jaw Clutch.—A clutch composed of two hub-like castings having jaws that engage each other. One hub is arranged to slide on its shaft as well as to rotate with it, so that it can be thrown in or out of gear.

Pulley Clutch.—An automatic device in the form of a grappling tongs for fastening a hoisting pulley to a beam.

Clutch Coupling.—See "Coupling."

Coarse Sand.—See "Sand."

Cobblestone.—A stone used in pavements, usually rounded like a pebble.

Cock.—A faucet or turn valve consisting of a tapering plug having a transverse hole through it for the passage of fluids. This plug fits into a hole, or seat, having a corresponding taper, so that in one position the passage-way is blocked and in another position it is opened.

Pet Cock.—A small cock used for draining pipes, etc.

Plug Cock.—A cock or a faucet which has a tapered plug, with a transverse hole, fitting into a prepared seat in a pipe.

Cocked-hat.—A coping projecting from the shaft of a pier above the elevation of high water, used for enlarging the lower portion of the pier and its base, thereby increasing the stability and reducing the foundation pressure.

Coefficient.—A constant factor in an algebraic expression.

Differential Coefficient.—The measure of the rate of change in a function relative to its variable. A term used in the calculus.

Empirical Coefficient.—A coefficient established by experience or observation rather than by scientific deduction from fundamental principles.

Coefficient of Contraction.—See "Contraction."
Coefficient of Elasticity.—See "Elasticity."
Coefficient of Expansion.—See "Expansion."
Coefficient of Friction.—See "Friction."
Coefficient of Impact.—See "Impact."
Coefficient of Lineal Expansion—See "Expansion."
Coefficient of Resilience.—See "Resilience."
Coefficient of Restitution.—See "Restitution."
Coefficient of Torsion.—See "Torsion."
Cofferdam.—A temporary enclosing structure, practically watertight, from which the water is pumped, and within which masonry or concrete is placed in the open air.
Movable Cofferdam.—A cofferdam constructed of timber, hinged at one corner and joined on the diagonal corner in such a way that it can be opened, after the pier is built, and moved away to another pier site.
Cog.—A tooth, catch, or projection on the periphery of a wheel.
Cog Wheel.—Same as "Gear," *q.v.*
Cohesion.—The force that holds together the individual particles of a body.
Coignet, Beton.—See "Beton-Coignet."
Coil Chain.—See "Chain."
Coil Friction Clutch.—See "Clutch."
Cold Chisel.—See "Chisel."
Cold-cut or **Cold Cutter.**—A cold chisel mounted on a handle like a hammer. It is used with the application of a maul.
Cold-hammering.—The act or practice of hammering metal when cold.
Cold-pressed. Pressed when cold. Applied generally to iron or steel.
Cold-pressed Paper.—See "Paper."
Cold-rolled.—Rolled when cold. Applied generally to iron or steel.
Cold-rolled Shafting.—See "Shafting."
Cold Saw.—See "Saw."
Cold-short.—The condition of brittleness in steel when it is cold; caused by excessive phosphorus.
Cold-short Iron.—See "Iron."
Cold-short Steel.—See "Steel."
Cold Shut.—See "Shut."
Cold-straightening.—The process of straightening metal when cold.
Collapsing Bucket.—See "Bucket."
Collar.—A flat ring surrounding anything closely.
Thrust Collar.—A collar on a shaft set to resist end thrust.
Collar Beam.—See "Beam."
Collision Post.—Same as "Collision Strut." See "Strut."
Collision Strut.—See "Strut."
Color.—A generic term referring inclusively to all of the colors of the spectrum, white and black, and all tints, shades, and hues which may be produced by their admixture.
Column.—A pillar or strut. A long member which resists compression.
Bethlehem Column.—A wide "H" column rolled in a four-roll mill by the Bethlehem Steel Company, similar to that of the "Bethlehem Beam," *q.v.*
Box Column.—A column made in the shape of a box, having sides of steel plates united by angles.
Channel Column.—A column made up of two channel-irons laced or stayed.
Closed Column.—A column that is boxed in, shutting out water and air, generally making the interior inaccessible for painting.

Column.

Gray Column.—A structural steel column composed of eight angle-irons riveted together in pairs, and stayed at short intervals by bent batten plates attached to the connected legs. The strut is in the form of a square cross, having the connected pairs of legs turned inward. Named after its inventor, John Gray, Esq., C.E.

Keystone Column.—A structural steel column made of four bent channels riveted together, with thimbles or nipples over the rivets separating the channels.

Long Column.—A column which will fail by buckling.

Nurick Column.—Same as the Keystone Column with the nipples or sleeves omitted.

Phoenix Column.—A fabricated column made up of rolled steel segments riveted together forming a circular section with either four or six exterior projections through which the rivets pass.

Pin-end Column.—A column that is free to turn at either end about a pin.

Short Column.—A column which will fail by crushing.

Spandrel Column.—A column resting on the extrados of an arch and supporting the roadway above.

Square-end Column.—A column bearing on its squared ends.

Z-Bar Column.—A fabricated column composed of four Z-bars and one web plate riveted together.

Columnar Fracture.—See "Fracture."

Columnar Pile.—See "Pile."

Column Bent.—See "Bent."

Column Crane.—See "Crane."

Column-foot.—The base of a column.

Column Footing.—See "Footing."

Combination Bridge.—See "Bridge."

Combination Dolly.—See "Dolly."

Combination Punch and Shears.—An apparatus which does both punching and shearing.

Combination Wrench.—See "Wrench."

Combined Bridge.—See "Bridge."

Combined Stress.—See "Stress."

Commercial Horsepower.—See "Horsepower."

Common Iron.—See "Iron."

Common Lime.—See "Lime."

Common Logarithm.—See "Logarithm."

Common Reamer.—See "Reamer."

Compass.—An instrument used to indicate the magnetic meridian or the direction of an object with reference to that meridian. An instrument for drawing circles.

Beam Compass.—A bar having two slides mounted thereon, one holding a steel point or centre, and the other the marking-pencil or pen—used for striking large circles.

Compensator.—An equalizing device on machines or engines.

Component.—A constituent part. One of the parts into which forces or stresses may be resolved or divided.

Horizontal Component.—A component of an oblique force taken in a horizontal line.

Longitudinal Component.—A component in a direction parallel to the plane of the trusses.

Transverse Component.—A component in a transverse direction, generally intended for a component perpendicular to the planes of the trusses.

Compound Curve.—See "Curve."

Compound Girder.—See "Girder."
Compound Locomotive.—See "Locomotive."
Compound Pulley.—See "Pulley."
Compound Stress.—See "Stress."
Compound Web Plate.—See "Plate."
Compression.—The state of being compressed; shortening by pressure.
Compression Joint.—See "Joint."
Compressive Strain.—See "Strain."
Compressive Strength.—See "Strength."
Compressive Stress.—See "Stress."
Compressor.—An apparatus for compressing liquids or gases.
Air Compressor.—A machine by which air is compressed into a receiver so that its expansion may be utilized as a source of power.
Computations.—Calculations; the figuring of bridgework.
Concave Brick.—See "Brick."
Concave Curvature.—See "Curvature."
Concentrated Load. -See "Load."
Concentrated Load Stress.—See "Stress."
Concentration.—A system of loading in which several loads are collected and applied at a point or over a very small area.
Axle Concentration.—The load from one axle of a locomotive or vehicle concentrated on a structure, or twice a wheel load.
Double Concentration.—A term descriptive of the method of figuring stresses in bridges for a live load, consisting of a string of cars of uniform weight per lineal foot headed by an excess load equal to the difference between the total weight of an engine and tender and the product of the length of the two by the weight per lineal foot of the cars, and followed by another similar and equal excess load two panel lengths (about fifty feet) back of the head of the train. This type of live load is no longer used, as it has been replaced by the "equivalent uniform live load."
Floor-beam Concentration.—The load transferred from one line of stringers to a floor-beam.
Single Concentration.—Similar to Double Concentration (*q.v.*) except that the second excess load is omitted. It, too, is no longer used.
Wheel Concentration.—The amount of load carried and delivered by one wheel.
Conchoidal Fracture. See "Fracture."
Concrete.—An artificial stone made by mixing some cementing material with an aggregate composed of hard, inert particles of varying size. Usually the cementing material is Portland cement, and the hard, inert particles are sand and broken stone, water being added to make the cement active.
Bituminous Concrete.—A concrete composed of bitumen, sand, and broken stone.
Broken Stone Concrete.—A concrete composed of cement, sand, broken stone, and water.
Cinder Concrete.—A concrete composed of cement, sand, cinders, and water.
Cyclopean Concrete.—Concrete in which large stones or boulders, sometimes called plums, have been bedded.
Gravel Concrete.—A concrete composed of cement, sand, gravel, and water.
Green Concrete.—Concrete that is fresh or has not yet gained its full strength.
Lead Slag Concrete.—A concrete made with lead slag in place of the usual broken stone.
Portland Cement Concrete.—Concrete in which Portland cement is used with water as the cementing material.
Reinforced Concrete.—Concrete in which steel bars are inserted to strengthen it, principally by resisting the tensile stresses induced by external forces.

Concrete.

Slag Concrete.—A concrete composed of cement, sand, water, and slag from the blast furnace.

Concrete Batch Mixer.—See "Mixer."

Concrete Continuous Mixer.—See "Mixer."

Concrete Floor.—See "Floor."

Concrete Girder.—See "Girder."

Concrete Masonry.—See "Masonry."

Concrete Mixer.—See "Mixer."

Concrete Pier.—See "Pier."

Concreting.—The act of mixing and placing concrete.

Concurrent Forces.—See "Force."

Condenser.—An apparatus for reducing gases or vapors to a liquid or solid form.

Ejector Condenser.—A form of condenser operated by the exhaust steam from the engine cylinder.

Hydraulic Condenser.—A chamber in which gas from a retort is cooled.

Injection Condenser, or Jet Condenser, or Siphon Condenser.—A form of condenser in which the injected water comes in contact with the steam.

Steam Condenser.—A condenser used for steam.

Conduit.—An underground, narrow passage. A medium or means for conveying. A pipe, tube, or underground passage carrying electric wires, etc.

Cone Clutch.—See "Clutch."

Cone Pulley.—See "Pulley."

Conical Gears.—See "Gears."

Conical Pulley.—See "Pulley."

Conical Roller.—See "Roller."

Conical Wheel.—See "Wheel."

Conjugate Stresses.—See "Stress."

Connecting Angle.—See "Angle."

Connecting Bar.—See "Bar."

Connecting Chord-heads.—Chord-heads used to connect bottom chord or web-channels to pins.

Connecting Plate.—See "Plate."

Connecting Rod.—See "Rod."

Conservation of Energy.—See "Energy."

Consolidation Locomotive.—See "Locomotive."

Construction Bolt.—See "Bolt."

Continuous Beam.—See "Beam."

Continuous Girder.—See "Girder."

Continuous Span.—See "Span."

Continuous Stringers.—See "Stringers."

Continuous Truss.—See "Truss."

Contour Line.—See "Line."

Contour Map.—Same as "Topographic Map." See "Map."

Contract.—An agreement between two or more parties for doing or not doing some definite thing.

Sub-Contract.—A contract which has been sublet.

Contraction.—The act of drawing together or shrinking. Diminishing the length, area, or volume of anything.

Coefficient of Contraction.—The ratio between the decrement of length, area of section, or volume and the original length, area of section, or volume. For temperature change, it is the same as the "Coefficient of Expansion," *q.v.* In hydraulics, it is the ratio between the area of the contracted section of a water-jet issuing from an orifice and the area of the orifice.

Contraction.

Lateral Contraction.—A lateral shrinking or shortening.

Contractor.—One who contracts or covenants either with the government or other public bodies, or with private parties to furnish supplies, or to construct works, or to perform any work or service at a certain price or rate.

General Contractor.—A principal contractor who sublets the whole or part of the whole contract.

Sub-Contractor.—One who takes a part or the whole of a contract from the principal contractor.

Contraflexure.—A reversal of bending in a column or beam.

Converted Iron.—See "Iron."

Converted Steel.—See "Steel."

Converter.—Same as "Bessemer Furnace." See "Furnace."

Convex Curvature.—See "Curvature."

Conveyor.—An apparatus or machine which carries material from one point to another.

Coordinate Paper.—See "Paper."

Coordinates.—A system of lines or angles, or both, by means of which the position of a point is determined by referring to certain fixed lines or points.

Origin of Coordinates.—The initial point in a system of coordinates to which other points are referred. In the rectangular system, it is the intersection of the two axes; in the polar system it is the point in the directrix about which the radius vector turns.

Polar Coordinates.—A system of coordinates in which the position of any point is defined by an angle and a distance from a fixed line and point.

Rectangular Coordinates.—A system of coordinates in which the position of any point is defined by its distances from two lines, called axes, making right angles with each other; or from three mutually perpendicular planes.

Semi-polar Coordinates.—A system of coordinates in which the radius vector of the polar system is combined with one of the coordinates of the rectangular system.

Cope.—To dress. To put a coping on a pier. To notch steel beams, channels, etc.

Cope Chisel.—Same as "Cape Chisel." See "Chisel."

Coping.—The top or cover of a wall, column, or pier. Usually made so as to project beyond the face below.

Starling Coping.—Same as "Cocked-hat," *q.v.*

Coping-machine.—A machine for notching structural shapes.

Coping Stone.—See "Stone."

Copper.—A reddish ductile metal having a specific gravity of 8.8 and a high conductivity for heat and electricity.

Corbel.—A small shelf cantilevered out from a beam, wall, or column in order to support a beam or a superincumbent load. Sometimes called a tassel or bragger.

Corbel Bolster.—See "Bolster."

Corbel Course.—See "Course."

Core.—To make or to cast a core. The inner part or filling of a wall. The internal mould in a casting.

Core Boring.—See "Boring."

Core Drill.—See "Drill."

Corner Bracket.—See "Bracket."

Cornice.—The projection at the top of a wall that is finished by a blocking course.

Corrosion.—The disintegration of a substance by the action of chemical agents.

Corrugated.—Bent or drawn into parallel furrows or ridges. Wrinkled; fluted.

Corrugated Bar.—See "Bar."

Corrugated Dolly.—See "Dolly."

Corrugated Iron.—See "Iron."

Corrugated Pile.—See "Pile."

Corrugated Plate.—See "Plate."

Cost.—The price paid or the expenditure involved in procuring or constructing anything.

Capitalized Total Cost.—A sum of money that includes the first cost of a structure, plant, etc., plus an amount the interest on which would cover the annual expenditures for operation, maintenance, and repairs.

First Cost.—The sum of all the expenditures made for investigation, promotion, engineering, and construction of a structure, plant, etc.

Maintenance Cost.—All expenditures for repairs and upkeep which are directly due to operating a structure or plant.

Operating Cost.—All expenditures incurred in running a plant or operating a structure not pertaining to upkeep nor to repairs.

Unit Cost.—The cost of a unit quantity of material or service.

Cotter.—A beveled piece of wood or steel, used as a wedge for fastening. Also a split steel key, used for the same purpose.

Cotter Bolt.—Same as "Cotter Pin." See "Pin."

Cotter Key.—Same as "Cotter," *q.v.*

Cotter Pin.—See "Pin."

Counter.—An adjustable diagonal in a truss, not subjected to stress except for certain partial applications of the live load.

Counterbalance.—To weigh against with an equal weight. Same as a counterpoise. Sometimes used as a synonym for counterweight, *q.v.*

Counterbore.—The reboring of a cylindrical hole for a part of its length to a larger diameter than the original.

Counterbrace.—A web diagonal which transmits a stress in the opposite direction (in relation to span-length) to that carried by the main diagonal of the same panel.

Counterfort.—A short cross-wall built behind the main wall to give it additional stability by acting as an anchor to hold back the main wall. Its action is opposite to that of a buttress.

Counterpoise.—Same as "Counterbalance," *q.v.*

Counter Shear.—See "Shear."

Countersink.—A drill or brace-bit for countersinking. To form by drilling or turning a conical cavity in timber, metal, or other material, for the reception of the head of a bolt, rivet, or screw, so that the end thereof may lie flush with the surface of the said material.

Countersink Drill.—See "Drill."

Countersinking Reamer.—See "Reamer.'

Counter Stress.—See "Stress."

Counter Strut.—See "Strut."

Countersunk Bolt.—See "Bolt."

Countersunk Rivet.—See "Rivet."

Counterweight.—A weight that counterbalances some other weight. To weight against. Similar to "Counterbalance," *q.v.*

Couple.—Two equal and parallel forces acting in opposite directions and in different lines.

Moment of a Couple.—The tendency of a couple to produce rotation, measured by the product of one of the two equal forces by the perpendicular distance between them.

Stress Couple.—A pair of equal and opposite stresses lying in the same plane.

Coupling.—The act of uniting and joining. The part that unites and joins.

Chain Coupling.—A hook connected to the end of a chain for the purpose of connecting it with another chain or object.

Claw Coupling.—A coupling in which the claws of one part fit into the recesses of the other part with a little amount of play; so that when the shafts are out of line, the coupling will accommodate itself to the obliquity without overstressing the shafts

Coupling.

Clutch Coupling.—A connection produced by means of a clutch.

Differential Coupling.—An extensible coupling designed for varying the speed of that part of the machinery which is driven.

Disk Coupling.—A permanent coupling consisting of two disks keyed on the connected ends of two shafts.

Flange Coupling.—A coupling made up of two parts, each firmly attached to the end of its shaft, bolted together to form a permanent connection.

Friction Coupling.—An adjustable connection consisting of a cone keyed rigidly to one shaft against which a movable part, having an interior conical surface, sliding on a feather on the other shaft can be pressed.

Jaw Coupling.—Same as a "Claw Coupling," *q.v.*

Joint Coupling.—A form of universal joint in which the sections are coupled and locked together.

Pipe Coupling.—A threaded sleeve into which are screwed the ends of the two pieces of pipe to be coupled.

Ratchet Coupling.—A shaft coupling consisting of a ratchet-wheel on one shaft turning a similar one on the other shaft.

Shaft Coupling.—Any of the several devices for joining the ends of two shafts.

Sleeve Coupling.—A permanent connection in which the coupling consists of a wide band of metal extending over both ends of the shafts to be joined.

Square Coupling.—A form of coupling box, consisting of two longitudinal halves, having a squared hole to fit the squared ends of the two shafts to be connected.

Coupling Box.—See "Box."

Coupling Link.—A link connecting two objects.

Coupling Pin.—See "Pin."

Coupling Valve.—A coupling having one end threaded to receive a metal pipe and the other with a shank to fit a hose.

Course.—A horizontal layer of stone in a masonry wall, or of a pavement.

Binder Course.—That portion of a pavement connecting the wearing surface to the base.

Corbel Course.—A course of brick or stone projecting from the face of a wall and forming a support for an eccentrically applied load.

Footing Course.—The bottom course of masonry at the base of a foundation.

Irregular Course.—A course in which the thicknesses of the stones vary at intervals.

Random Course.—Same as "Irregular Course," *q.v.*

Regular Course.—A course in which the thickness of stones is uniform throughout.

Ring Course.—A course of masonry parallel to the face of the arch.

Rubble Course.—A course in which rough stones are leveled off at specific heights to an approximately horizontal surface.

Stretcher Course.—A course of masonry consisting entirely of stretchers.

String Course.—A narrow ornamental course carried around a structure.

Coursed Rubble.—See "Rubble."

Coursing Joint.—See "Joint."

Cover Plate.—See "Plate."

Crab.—A short shaft or axle, mounted in a frame, having squared ends to receive hand cranks, used to wind up a rope and thereby raise a load.

Bracket Crab.—A hoisting apparatus fastened to a wall.

Derrick Crab.—A hoisting apparatus at the foot of a derrick. A special crab for a derrick.

Hoisting Crab.—Any crab used for hoisting.

Square Crab or Square End Crab.—A crab having the ends of the shaft squared to receive the cranks or handles.

Cradle.—A term applied to various kinds of timber supports, which partly enclose the mass sustained. To incline suspending cables to the vertical. See "Cradling."

Cradling.—The placing of the cables in a suspension bridge so that they are closer at the sag than at the supporting towers.

Cramp.—A short bar of metal having its two ends bent downward at right angles for insertion into two adjoining pieces of stone, wood, etc., to hold them together.

Cramp Iron.—Same as a "Cramp," *q.v.*

Cramp Joint.—See "Joint."

Crandall.—A mason's tool consisting of an iron bar for the handle, having a slot near one end into which are keyed a number of double-headed mason's points. Also to dress stone with a crandall.

Crandalled Dressing.—See "Dressing."

Crandalled Masonry.—See "Masonry."

Crane.—A hoisting machine mounted so that it can move in a horizontal direction and thereby place the load at any point within its range.

Balance Crane.—A crane having two counterpoised arms.

Cantilever Crane.—A crane in which the weight to be lifted is balanced by a heavy mass of material such as stone blocks or pig iron. It is generally capable of being rotated, the rear end being supported by a circular track.

Column Crane.—A crane built in the form of a latticed column with a curved overhang at the top. Also called a "Tower Crane."

Derrick Crane.—A crane in which the post is supported by fixed stays in the rear, the jib being pivoted like the boom of a derrick.

Electric Crane.—A crane operated by electricity.

Gantry Crane.—A crane set upon a gantry, *q.v.*

Hydraulic Crane.—An apparatus for raising and lowering loads acting on the principle of a hydraulic press.

Jib Crane.—A crane having a swinging boom.

Locomotive Crane.—A locomotive, or steam engine on wheels, with a crane attached. Used in yard work.

Overhead Balanced Crane.—A combination of an overhead and a balanced crane.

Overhead Crane.—A crane which travels on elevated girders in a shop.

Rotary Crane.—A crane having a jib swinging in a complete circle.

Steam Crane.—A crane operated by steam power.

Swinging Crane.—Any crane which has a boom that swings laterally.

Tower Crane.—Same as "Column Crane," *q.v.*

Tram Crane or Traveling Crane.—A crane mounted on wheels and capable of being moved from place to place.

Walking Crane.—Same as "Locomotive Crane."

Water Crane.—A crane operated by means of hydraulic pressure.

Crane Girder.—See "Girder."

Crank.—A device or mechanism for producing rotation about an axis. Its usual form is a bar or disk set at right angles to the shaft and containing a crank-pin, remote from the axis of rotation, to which the force is applied. An iron brace or support. A twist or a turn.

Bell Crank.—An L-shaped lever by which the direction of motion is changed ninety degrees, or more or less, and by which the velocity ratio and range may be altered at pleasure through making the arms of different lengths.

Disk Crank.—A disk carrying a crank-pin and substituted for a crank.

Crank Auger.—See "Auger."

Crank Pin.—See "Pin."

Crank Shaft.—See "Shaft."

Creeper Traveler.—See "Traveler."

Creosote.—An oily product obtained from distilled coal-tar with the addition of caustic soda and sulphuric acid.

Creosoted Lath.—See "Lath."

Creosoted Timber.—Timber that has been thoroughly saturated with creosote oil or dead oil.

Crescent Truss.—See "Truss."

Crest.—The top of an embankment. Also the highest water in a flood.

Crib.—An inner lining of a shaft or well, consisting of a frame or box of timbers and a backing of planks, to keep the earth from caving in. To build up a support by placing heavy timbers in layers, the sticks of the consecutive layers generally running in directions at right angles to each other. That portion of the base of a pier lying between the top of the deck above the working chamber and the neat work of the shaft.

Basket Crib.—A form for pier foundations in the shape of a basket. This type was used on the Chelsea Bridge at Boston.

Open Crib.—A crib open at the top and bottom.

Cribbing.—Timbers piled cross-wise in order to form a support for a load.

Crimp.—To offset an angle by bending so that it will fit over the flange of another angle, thus doing away with filler plates beneath.

Crimping-machine.—A machine which crimps angles. Used in bridge shops.

Cripple.—To disable or to weaken. Also to give or to give way.

Crippling Load.—See "Load."

Crippling Stress.—See "Stress."

Critical-speed.—That speed of a train on a bridge which produces the maximum impact.

Cross Beam.—See "Beam."

Cross Bond.—See "Bond."

Cross Bracing.—See "Bracing."

Cross-cut Saw.—See "Saw."

Cross Fibered Wood.—See "Wood."

Cross Frame.—See "Frame."

Cross Girder.—See "Girder."

Cross-grained.—Of irregular or gnarled condition. Applies to timber.

Cross-grained Wood.—See "Wood."

Cross-hairs.—Two very fine hairs or strands of spider's web stretched at right angles to each other across the focal plane in a transit or level.

Cross Hatch.—See "Hatch."

Cross-head.—A machine element having the shape of a "T" or a cross, and running on guides in order to control and steady the motion of another member. Often used on piston rods.

Cross-head Pin.—See "Pin."

Crossing.—An intersection. The place where two roads or railroads cross. The place where a river or stream may be crossed. The term is often used for the bridge crossing the stream or river.

Grade Crossing.—A crossing where both roads or tracks are at the same elevation.

Oblique Crossing.—A crossing in which the intersecting centre lines make an oblique angle with each other.

Overhead Crossing.—A crossing where one road or track is above the other.

Skew Crossing.—Same as "Oblique Crossing," *q.v.*

Square Crossing.—A crossing in which the intersecting centre lines are perpendicular to each other.

Under Crossing.—A crossing where one of the roads or tracks is below the other.

Cross-over.—A connection between two parallel tracks.

Cross Riveting.—See "Riveting."

Cross-section.—See "Section."
Cross-section Book.—A surveyor's field book ruled specially for plotting cross-sections.
Cross-section Paper.—See "Paper."
Cross-section Rod.—See "Rod."
Cross Tie.—See "Tie."
Cross-wires.—Two very fine wires set at right angles to each other across the focal plane of a level or transit. Similar to "Cross-hairs," *q.v.*
Crow Bar.—See "Bar."
Crow-foot Seam.—See "Seam."
Crown.—The top or summit of the curved cross section of a roadway pavement; the centre being made higher than the sides to facilitate draining the roadway. The top of an arch ring.
Crowning Pulley.—See "Pulley."
Crown Thrust of Arch.—See "Arch."
Crown Tile.—See "Tile."
Crown Valve.—See "Valve."
Crown Wheel.—See "Wheel."
Crucible Cast Steel.—See "Steel."
Crucible Steel.—See "Steel."
Crusher.—A machine that crushes or applies a load sufficient to overcome the compressive resistance of any substance; for example, a "rock-crusher."
Crushing.—The breaking down of a material due to the application of a load.
Modulus of Crushing.—A number denoting the average value of the crushing resistance of a material.
Crushing Strain.—See "Strain."
Crushing Strength.—See "Strength."
Crystalline.—Consisting of crystals. Relating or pertaining to crystals. Having a definite structure referable to one of the crystallographic systems.
Crystalline Fracture.—See "Fracture."
Cubature.—The cubic measure or contents of anything.
Cubic Curve.—See "Curve."
Cull.—To sort out or select material that does not meet the requirements of the specifications. Any piece that has been culled.
Culvert.—A small covered passage for water under a roadway or embankment.
Arch Culvert.—A culvert having an arch roof.
Box Culvert.—A square or rectangular shaped culvert.
Dive Culvert.—An inverted siphon.
Cumulative Stress.—See "Stress."
Cumulative Vibration.—See "Vibration."
Cup and Ball Joint.—See "Joint."
Cup Dolly.—See "Dolly."
Cup Fracture.—See "Fracture."
Cup Washer.—See "Washer."
Curb.—A broad, flat, circular ring of wood, iron, or stone placed under the bottom of a circular wall, as in a shaft or well, to prevent unequal settlement. The outer casing of a turbine wheel. The edge of a sidewalk next to the main roadway. The wheel-guard in a bridge. To strengthen or protect by means of a curb.
Curb Chain.—See "Chain."
Curb Girder.—See "Girder."
Curb Stone.—See "Stone."
Curled Wood.—See "Wood."
Current.—The flow of a liquid or gas, or the movement of electricity.
Air Current.—The moving of air through space or through a conduit.

Current.

Alternating Current.—An electric current of which the direction of flow reverses a given number of times per second.

Direct Current.—An electric current which flows in the same direction constantly.

Water Current.—A flow of water.

Current Meter.—See "Meter."

Curtain Wall.—See "Wall."

Curvature.—The amount of curving or bending of a line, figure, or body. It is measured by the ratio of the deflection angle between end tangents (measured in radians) to the length of the intervening arc.

Concave Curvature.—The direction of curvature as seen from a point on the chord joining the extremities of the arc. Opposed to Convex Curvature.

Convex Curvature.—The direction of curvature as seen from a point on a tangent to the curve. Opposed to Concave Curvature.

Degree of Curvature.—The angle in degrees subtended by a chord one hundred feet long. Used in railroad location.

Radius of Curvature.—The radius of the circle of curvature.

Curve.—A line continuously bent so that no portion of it is straight. A continuous bending; a flexure without angles. A drafting instrument for drawing curved lines.

Adiabatic Curve.—A curve exhibiting the relation between the pressure and volume of a fluid upon the assumption that there is no transmission of heat during expansion or contraction.

Algebraic Curve.—A curve in which the equations in linear coordinates contain only the algebraic functions of the coordinates.

Catenary Curve.—Same as a "Catenary," *q.v.*

Characteristic Curve.—A curve which shows the relation existing between certain features or properties of a machine or substance.

Compound Curve.—A continuous curve composed of two or more arcs having different radii.

Cubic Curve.—A curve of the third degree.

Cuspidal Curve.—A curve ending in or shaped like a cusp, *q.v.*

Cycloidal Curve.—Same as "Cycloid," *q.v.*

Easement Curve.—A curve of gradually changing radius for passing from a tangent to a circular curve. Used in railroading to ease the train shock that comes from the changing of the direction of motion.

Efficiency Curve.—A curve showing the relation of output to input, or the efficiency of a machine, apparatus, method, etc.

Elastic Curve.—The curve formed by the neutral axis of a beam, as it deflects under the action of its own weight, and of the loads upon it.

Elliptical Curve.—Same as "Ellipse," *q.v.*

Epicycloidal Curve.—Same as "Epicycloid," *q.v.*

Evolute Curve.—Same as "Evolute," *q.v.*

Harmonic Curve.—Same as "Sine Curve," *q.v.*

Hyperbolic Curve.—Same as "Hyperbola," *q.v.*

Inverted Catenary Curve.—A curve formed by revolving the ordinary catenary one hundred and eighty degrees around its major axis.

Involute Curve.—Same as "Involute."

Irregular Curve.—A draftsman's tool for drawing curved lines of varying radii.

Lemniscatic Curve.—Same as "Lemniscate," *q.v.*

Logarithmic Curve.—A curve in which the ordinate are logarithms of the corresponding abscissæ.

Logarithmic Spiral Curve.—A spiral curve in which the radius vector varies as the logarithm of the angles.

Curve.

Mechanical Curve.—Same as "Transcendental Curve," *q.v.*

Neutral Curve.—The curve of the neutral axis of a loaded beam.

Ogee Curve.—A reverse curve formed by the union of two circular arcs of opposing curvature, used in architecture.

Oval Curve.—Same as "Oval," *q.v.*

Parabolic Curve.—Same as a "Parabola," *q.v.*

Periodic Curve.—A curve which represents a repeating, or periodic function.

Plane Curve.—A curve lying in one plane.

Railroad Curve.—Curve used on railways or railway work. Also a draftsman's tool or template for drawing such curves.

Regular Curve.—Same as a "Simple Curve," *q.v.*

Reverse Curve.—A continuous curve formed of two arcs of opposing curvature.

Simple Curve.—In railroad work a circular arc extending from one tangent to the next; a curve of constant radius.

Sine Curve.—A curve in which the abscissa is proportional to the angle, and the ordinate is proportional to the sine of the angle.

Spiral Curve.—Same as "Spiral," *q.v.*

Transcendental Curve.—A curve expressed by an equation containing transcendental functions of one or more of the ordinates.

Transformed Catenary Curve.—Same as "Transformed Catenary." See "Catenary."

Transition Curve.—Same as "Easement Curve," *q.v.*

Vertical Curve.—A curve in a vertical plane, usually a parabola, connecting two grade tangents of a roadway or railroad.

Curved Girder.—See "Girder."

Curved Line.—See "Line."

Curved Top Chord.—See "Chord."

Cushing Pile.—See "Pile."

Cushion.—A confined body of air or steam which serves under pressure as a buffer to absorb impact.

Air Cushion.—A buffer using air to absorb impact of a moving mass and gradually to bring it to rest.

Cushion-coat.—A layer of material used in pavements, from one-half to one inch thick, placed between the wearing surface and the foundation.

Cusp.—A point in a curve where two branches have a common tangent. The intersection of two curves.

Cuspidal Curve.—See "Curve."

Cut Gear.—See "Gear."

Cut Nail.—See "Nail."

Cut-off.—A device for cutting off the passage of steam from the steam chest to the cylinder of an engine. A channel cut through a narrow neck of land to straighten a river. That point where piles or timbers are sawed off after being put in place.

Cut-off End.—That part of a pile that has been sawed off or wasted after the pile is in place.

Cut Spike.—See "Spike."

Cut Stone.—See "Stone."

Cut Stone Masonry.—See "Masonry."

Cutter.—A steel tool for cutting metals. Also the cutting edge on a cutting machine.

Bar Cutter.—A shearing machine which cuts metallic bars into lengths.

Cold Cutter.—Same as "Cold-cut," *q.v.*

Glass Cutter.—A hand tool having a diamond edge wheel mounted on a shaft, used for cutting glass.

Cutter.

Hot Cutter.—A tool for cutting metal which has been softened by heating.

Pinhole Cutter.—An apparatus for cutting pinholes in the chords or web members of a truss.

Pipe Cutter.—A plumber's tool consisting of two beveled edged steel cutting wheels mounted in an adjustable jaw that partly encircles the pipe. A rotation of the tool by a suitable handle and the closing up of the jaws severs the pipe.

Pneumatic Cutter.—A cutter operated by compressed air.

Rivet Cutter.—A hand tool, similar to a cold-cut but with edge sharpened on a more obtuse angle, used for cutting off the heads of driven rivets.

Stone Cutter.—A workman skilled in the art of cutting and dressing stone.

Thread Cutter.—A tool, consisting of a stock and set of dies, used for cutting threads on rods and pipes.

Cutting Edge.—The edge of the tool which does the cutting. The edge of timber or steel angles placed on the bottom of the working chamber of a caisson.

Cutting Tool.—See "Tool."

Cutwater.—A starling; the projecting ends of a bridge pier, etc. Usually so shaped as to allow water, ice, drift, etc. to strike without injury to the structure.

Cycle.—A complete revolution. Any recurring period in which a series of events or phenomena takes place. A series that repeats itself. A series of operations by which any product is finally restored to a primary condition.

Cycloid.—A curve generated by a point on the circumference of a circle when the circle is rolled along a straight line and kept always in the same plane.

Cyclopean Concrete.—See "Concrete."

Cylinder.—A solid of revolution generated by a rectangle rotating about one of its sides. A machine element having a circular bore.

Air Cylinder.—A nearly air-tight hollow cylinder having a piston moving in it.

Steam Cylinder.—The chamber of a steam engine in which the force of steam is exerted on a piston.

Water Cylinder.—The cylinder in a pump by means of which and the moving piston therein water is forced into an exterior main.

Cylinder Pier.—See "Pier."

D

Damper.—A door or valve for admitting air to a furnace

Dangerous Section.—See "Section."

Dap.—To notch a timber on its bearing.

Dapped Joint.—See "Joint."

Dash-pot.—A cylinder containing a loosely fitted piston and partly filled with fluid, used to check sudden movements in the parts of a machine.

Datum.—A fact either indubitably known or treated as such for the purpose of a particular discussion. A known reference. A point, line, or plane used as a basis for referring measurements.

Datum Line.—See "Line."

Datum Plane.—See "Plane."

Day Foreman.—See "Foreman."

Day Superintendent.—See "Superintendent."

Deadening Dressing.—See "Dressing."

Dead Load.—See "Load."

Dead Load Stress.—See "Stress."

Dead-man.—A timber, log, or beam buried in the ground for anchorage.

Dead Melt.—See "Melt."

Dead-points.—The two points in the revolution of a crank where the crank arm is parallel with the rod which connects it with the moving power.

Dead Pulley.—Same as "Loose Pulley," *q.v.*

Deck.—The flooring of a bridge.

Double Deck.—A condition of a span having two decks, one over the other.

Intermediate Deck.—A deck between two other decks, or at some distance vertically from either chord.

Lifting Deck.—A deck without trusses which raises or lowers vertically.

Lower Deck.—The bottom deck of a span.

Upper Deck.—The top deck of a span.

Deck Beam.—See "Beam."

Deck Bridge.—See "Bridge."

Deck Cantilever.—See "Cantilever."

Deck Girder.—See "Girder."

Decking.—Flooring. Same as "Deck," *q.v.*

Deck Plate Girder.—See "Girder."

Deck Span.—See "Span."

Deck Truss.—See "Truss."

Declivity.—A downward slope or descent of the ground.

Deflection.—A lateral motion, a motion at right angles to the length of the piece. Also the amount of such motion expressed in some lineal unit as inches.

Dynamic Deflection.—The additional deflection caused by the live load being in motion.

Static Deflection.—Deflection due to a quiescent load.

Deflection Indicator or **Deflectometer.**—An apparatus for measuring the deflection of bridge spans.

Deformation.—Change of form. A change of shape in a member or combination of members without any breach of the continuity of its parts.

Elastic Deformation.—A change of shape without impairment of the elastic properties of the material. A deformation with resulting stress inside of the elastic limit.

Residual Deformation.—Deformation left in a member after the forces causing same have been removed. Same as Permanent Set.

Truss Deformation.—An alteration in the lengths and positions of the members composing a truss.

Deformed Bar.—See "Bar."

Density. The mass or amount of matter per unit of volume.

Departure.—A term used in surveying to denote the perpendicular distance from one of two assumed rectangular coordinates—often from the one running north and south.

Depreciation.—The loss of value in a plant or structure during a course of years as measured by the difference between its first cost and its salvage value at the end of the allotted time.

Depth.—The downward distance from the surface or top. The term generally carries the idea of verticality; but such is not always the case; for instance, the depth of any beam that is inclined to the horizontal is measured in a direction perpendicular to its length, and, therefore, on a line inclined to the vertical.

Arch Depth.—The depth of the arch ring at any point at right angles to the axis.

Economic Depth.—That depth of truss or girder, which, when everything is considered, will give results that are satisfactory from all standpoints and involving the least expenditure of money for properly combined first cost, operation, maintenance, and repairs.

Effective Depth.—The perpendicular distance between the gravity lines of a truss or girder.

Truss Depth.—The vertical distance between the centre lines of the upper and lower chords.

Derailing Apparatus.—A device or mechanism used for derailing trains.

Derailing Switch.—See "Switch."

Derrick.—An apparatus for lifting and moving heavy weights. It is similar to the crane; but differs from it in having the boom, which corresponds to the jib of the crane, pivoted at the lower end so that it may take different inclinations.

Bull-Wheel Derrick.—A derrick with a bull wheel attached to the bottom of the mast in order to swing the derrick by ropes running to the hoisting engine.

Floating Derrick.—A movable derrick erected on a special boat, barge, or vessel.

Gin Pole Derrick.—See "Gin Pole."

Gin Type Derrick.—A framework with four stiff legs, used in borings, or for lifting pipes in trenches.

Guy Derrick.—A derrick in which the mast is guyed with cables to an anchorage.

Stiff Leg Derrick.—A derrick where stiff legs, usually of timber, take the place of guy lines for staying the mast. These stiff legs are attached to horizontal timbers which in turn are fastened to the bottom of the mast.

Design.—To proportion all the parts of a structure. A plan, or plans, showing the various parts of a structure, their sizes, and relations.

Detail.—One of the smaller parts into which any construction or design may be divided. To go into particulars. To draw the particular parts.

Detail Drawing.—See "Drawing."

Detailing.—The actual work of planning and drawing the different parts and the connections of any structure. The smaller parts of any construction, speaking of them as a class.

Detail Paper.—See "Paper."

Deviation.—The variation or deflection from a straight line or course.

Diagonal.—A member running obliquely across the panel of a truss. Any oblique line.

Lateral Diagonal.—A diagonal member in a lateral system.

Main Diagonal.—A web diagonal member joining the top and bottom chords of a truss, and taking its greatest stress when not less than one half of the span is covered by the live load.

Sub Diagonal.—An intermediate web diagonal joining a chord with a main diagonal.

Diagonal Bracing.—See "Bracing."

Diagonal Tie.—See "Tie."

Diagonal Wrench.—See "Wrench."

Diagram.—A sketch, outline, or skeleton drawing. A record made by curves plotted on cross-section paper.

Clearance Diagram.—A diagram used in bridge designing showing the horizontal and vertical clearances in a structure.

Displacement Diagram.—A diagram in which the relative position of points represents in magnitude and direction the relative displacement of particles.

Double Tracing Diagram.—A diagram on cross-section paper containing two related groups of curves, and involving four variable quantities. See Figs. 55*uu* and 55*vv*.

Erection Diagram.—A skeleton drawing of a truss or span showing all pieces in their relative positions, properly lettered and numbered in order to facilitate the process of erection.

Force Diagram.—A diagram in which the amounts and directions of forces are represented by lines for the purpose of finding their resultant.

Frame Diagram.—A diagram of a frame in which the positions of the axes of the joints are shown by points, while the rigid connections are shown by lines between them.

Graphic Diagram.—A diagram in which lines are drawn to represent the elements of a problem.

Indicator Diagram.—The diagram showing the relation between pressure and piston travel in an engine cylinder, as traced by indicator.

Diagram.

Load Diagram.—A diagram showing the amounts and arrangement of loads on a structure. The diagram taken off an engine by an indicator.

Locomotive Diagram.—A diagram showing the wheel loads and spacings in a locomotive.

Moment Diagram.—A curve showing the values of the bending moments in a beam or truss at various sections thereof.

Packing Diagram.—A drawing showing the arrangement or packing of the parts of a composite member or the disposition of several members meeting at a panel point. Refers generally to arranging truss members on pins in pin-connected structures.

Shear Diagram.—A diagram showing the variation of the shear along a beam or truss.

Skeleton Diagram.—A diagram which shows the general peripheral outline and the main members in a truss.

Stress Diagram.—A skeleton drawing of a truss, upon which are written the stresses in the different members. Also called "Diagram of Stresses."

Williot Diagram.—See "Williot Diagram."

Diagram of Stresses.—Same as "Stress Diagram," *q.v.*

Diagram of Weights.—A system of right lines or curves giving the weights of metal or portions of same per lineal foot of structure for bridges, trestles, etc.

Diametral Pitch.—See "Pitch."

Diametral Plane.—See "Plane."

Diamond Drill.—See "Drill."

Diaphragm.—A thin plate or partition across a bridge member to stiffen the same.

Diaphragm Plate.—See "Plate."

Die.—A steel former or device for shaping, impressing, or cutting out something.

Pipe Die.—A tool for cutting threads on a pipe.

Dies.—Two flat plates of hardened steel having a semi-circular groove cut in the edges making contact with each other. This groove has an internal thread, so that when the two pieces are brought together in a stock a female screw is formed. It is used for cutting threads on rods, bolts, etc.

Die Stock.—See "Stock."

Differential.—An infinitesimal difference between two values of a variable quantity. Also often used for the expression "differential gear."

Differential Block.—See "Block."

Differential Capstan.—See "Capstan."

Differential Coefficient.—See "Coefficient."

Differential Coupling.—See "Coupling."

Differential Gear.—See "Gear."

Differential Jack.—See "Jack."

Differential Pulley.—See "Pulley."

Differential Screw Jack.—See "Jack."

Differential Tackle.—Same as "Differential Block," *q.v.*

Differential Windlass.—See "Windlass."

Dike or Dyke.—A mound of earth built to prevent the overflow of rivers or of the sea; also to keep the channels of rivers, streams, etc., in one position. A timber construction to protect a river bank against erosion or to form land by deposition of sediment.

Puddle Dyke.—A dyke with a puddle wall running longitudinally through it.

Dimension.—Bulk, size, extent, or capacity. The length, width, height, etc., in units of measure.

Dimension Stone.—See "Stone."

Dinkey Engine.—Same as "Dinkey Locomotive." See "Locomotive."

Dinkey Locomotive.—See "Locomotive."

Dip.—The inclination to the horizontal of any stratum of earth or rock.

Dipper Dredge.—See "Dredge."

Direct Stress.—See "Stress."

Direct Tension.—See "Tension."

Direct Wind Load Stress.—See "Stress."

Disc or **Disk.**—A flat circular piece of material.

Screw Disc.—A plate or casting circular in plan, shaped like the thread of a screw, or having a helicoidal surface.

Discharge.—A flowing out. Used in connection with the amount of liquid passing through an orifice in a unit of time, or the amount of water in a stream passing a given cross-section in a unit of time.

Discharge Valve.—See "Valve."

Discount.—An amount deducted from a sum owing, or to be paid. To deduct such a sum of money.

Bank Discount.—The advanced payment of interest demanded by the bank at the time of making a loan. It is computed as simple interest on the face value of the note for the time given.

True Discount.—The present worth of the interest computed on the face value of the note.

Disk.—Same as "Disc," *q.v.*

Disk Coupling.—See "Coupling."

Disk Crank.—See "Crank."

Disk Pile.—See "Pile."

Displacement Diagram.—See "Diagram."

Ditch.—A trench made by digging. A narrow open passage for water on the surface of the ground.

Dive Culvert.—Same as "Syphon," *q.v.*

Diving-bell.—A mechanical contrivance consisting of an inverted, or bell-shaped, chamber filled with compressed air in which persons are lowered beneath the water for the examination of the foundation of bridges, etc.

Diving Dress or **Diving Suit.**—A submarine armor used for the same purpose as that of a diving bell, *q.v.*

Division Wall.—See "Wall."

Dock.—An enclosed, or partially enclosed, water-space in which vessels, barges, etc., are loaded and unloaded.

Dry Dock.—A dock from which water is withdrawn after the vessel is floated in for repairs.

Wet Dock.—A dock where vessels are placed to load and unload.

Dog.—A name for various mechanical devices, tools, etc., that usually grip something. The grappling iron which lifts the monkey, or hammer, of a pile driver. Any part of a machine acting as a claw or clutch. A click or pallet which restrains the back action of a ratchet wheel.

Bench Dog.—A hook-shaped iron fastened to a bench for holding in place materials, such as wood.

Cant Dog.—Same as "Cant Hook," *q.v.*

Chain Dog.—A lumber chain having on each end a hook to be driven into logs that go to make up a raft.

Eye-bar Dog.—A special pair of tongs for lifting and moving eye-bars.

Girder Dogs.—A special pair of dogs used for lifting and moving girders.

I-Beam Dog.—A special pair of dogs for lifting and moving I-beams.

Raft Dog.—An iron bar with ends bent over and pointed for securing logs together in a raft.

Ring Dogs.—A pair of dogs connected by a ring.

Dog.

Sling Dogs.—A pair of dogs that have the outer ends of a cable sling fastened to the straight ends of the dogs.

Span Dogs.—Same as "Ring Dogs," *q.v.*

Timber Dogs.—A special pair of hooks for hoisting and moving timber.

Dog Head.—See "Head."

Dog Hook.—See "Hook."

Dog Iron.—A short bar of iron forming a kind of cramp with its ends bent down at right angles and pointed so as to hold together the two pieces into which they are driven. Often the term ' Dog Iron" is used for "Dog Hook."

Dolly.—An extension piece placed on the upper end of a pile when the head of the pile is below the leads of the pile driver and out of reach of the hammer. A follower. A snap head; a tool with an indented head for holding the head of a rivet and absorbing impact while the other head is being driven.

Air Dolly.—A dolly operated by compressed air. Used between two beams.

Bar Dolly.—A goose-neck or horse-dolly which has an indentation for a rivet head at each end.

Bent Club Dolly.—A club dolly having a bend in the hammer or anvil.

Bent Dolly.—A dolly with a bent offset at the centre and only one end having the cup-shaped indentation for the rivet heads

Club Dolly.—A dolly with a steel hammer head and an iron handle attached. The smaller end of the hammer head has a cup-like indentation for holding the rivet head. Usually a maul is held against the big end of the hammer head while rivets are being driven.

Combination Dolly. -A double headed tool used for driving four different sizes of rivets. Usually balanced on a chain.

Corrugated Dolly.—A straight dolly with one cupped end, the other being an oval knob.

Cup Dolly.—Any dolly that has a cupped end for receiving rivet heads.

Flat Dolly.—A hammer headed dolly, flat on both faces for flattening rivet-heads.

Goose-neck Dolly.—A dolly that has a quickly curved bend near one end, with both ends arranged for receiving rivet heads.

Heel Dolly.—A tee-headed dolly, having the far end rounded with a hole for a seven-eighths (⅞) inch bolt located one and seven-eighths (1⅞) inches away from the centre of the tee head. Also a dolly with a long shaft and a short right-angled bend at one end, the cup being in the short end.

Horse Dolly.—Same as a "Goose-neck Dolly," *q.v.*

Ring Dolly.—A dolly having a handle attached to two circular plates. These plates have a series of holes near the circumference on one side and a bucking bar on the other. A tap bolt goes through any of the holes and fastens to the handle, thus placing the bucking bar at any angle required.

Screw Dolly.—A straight dolly with a shaft that screws into the head. Used between beams for bucking up.

Spring Dolly.—A dolly having a heavy hammer head attached to a long handle. Each end of the hammer has a cup to receive the heads of the rivets during driving.

Straight Dolly.—A cup-shaped dolly with a straight head and shank.

Dolly Bar.—See "Bar."

Dolomitic Limestone.—See "Limestone."

Dolphin.—A cluster of piles driven some distance ahead of the ends of the channel span piers of an opening bridge to protect the faces of the piers against blows from passing vessels.

Donkey Engine.—See "Engine."

Donkey Pump.—See "Pump."

Dorchester Sandstone.—See "Stone."
Doty Tie.—See "Tie."
Double Bitted Axe.—See "Axe."
Double Blocks.—See "Blocks."
Double Bowstring Truss.—See "Truss."
Double Cancellation.—See "Cancellation."
Double Cap.—See "Cap."
Double Concentration.—See "Concentration."
Double Deck.—See "Deck."
Double Drill.—See "Drill."
Double Ender Locomotive.—See "Locomotive."
Double End File.—See "File."
Double-faced Hammer.—See "Hammer."
Double Flemish Loop Knot.—See "Knot."
Double Intersection.—Same as "Double Cancellation," *q.v.*
Double Intersection Truss.—See "Truss."
Double Joint.—See "Joint."
Double Knot.—See "Knot."
Double Lacing. See "Lacing."
Double Latticing.—Same as "Latticing," *q.v.*
Double Locomotive Excess-load.—See "Locomotive Excess-load."
Double Piston Locomotive.—See "Locomotive."
Double Refined Iron. See "Iron."
Double Rim Bearing Draw.—See "Draw."
Double Rim Bearing Turntable.—See "Turntable."
Double Riveted Lacing.—See "Lacing."
Double Riveting. See "Riveting."
Double Rotating Cantilever Draw.—See "Draw."
Double Shear. See "Shear."
Double Shear Steel. See "Steel."
Double Speed Pulley.—See "Pulley."
Double Triangular Truss.—See "Truss."
Double Truck Tank Locomotive.—See "Locomotive."
Double Wrench.—See "Wrench."
Douglas Fir.—A species of the pine family found on the Pacific Coast. Grows very large and furnishes hard durable timber.
Dovetail.—A manner of making joints by having a series of projections in one piece fitting into corresponding recesses in another piece. A joint in carpenter work. It is a poor joint in timber where much stress has to be provided for. The shape of the tongue of the joint is like that of the spread tail of a dove.
Dovetail Joint.—See "Joint."
Dowel.—A straight pin of wood or metal driven part way into each of the two faces which it unites. Also called a dowel-pin.
Dowel Joint.—See "Joint."
Dowel Masonry.—See "Masonry."
Draft.—The depth to which a floating vessel or box sinks in the water. Also a cut or a groove.
  Chisel Draft.—A tool used for drafting stone. The cut in stonework made by such a tool—generally at the edges of the stones.
  Margin Draft.—A chisel draft around the edges of a stone.
Drafted Dressing.—See "Dressing."
Drafted Stone.—See "Stone."
Drainage.—The run-off in a drainage area. A system of piping to carry off water.
Drainage Area.—See "Area."

Draught.—A drawing. A narrow level strip which a stone-cutter first cuts around the edges of a rough stone, to guide him in dressing off the face thus enclosed by the draught. To make drawings. Spelled also "draft."

Draw.—The movable portion of a draw-bridge. To make drawings. To haul.

Centre Bearing Draw.—A swing span supported on a central pivot.

Double Rim Bearing Draw.—A draw span supported on two rims or a double drum.

Double Rotating Cantilever Draw.—A movable structure composed of two adjacent swing spans, the inner ends of which are mechanically connected, and the outer ends of which engage with anchorages.

Revolving Draw.—A draw which turns in a horizontal plane.

Rim Bearing Draw.—A swing span supported on a rim or drum.

Rotating Draw.—Same as "Revolving Draw," *q.v.*

Wedge Bearing Draw.—A swing span in which the live load, or a portion thereof, is carried by wedges under the chords of the trusses.

Draw Bridge.—See "Bridge."

Drawing.—The act of pulling or hauling. The making of a plan on paper, etc. Also the plan itself.

Detail Drawing.—A drawing on a large scale showing all small parts, dimensions, details, etc.

Erection Drawing.—Same as "Erection Diagram." See "Diagram."

General Drawing.—A drawing showing the elevation, plan, and cross-section of the structure—also the borings for substructure and the main dimensions.

Perspective Drawing.—A drawing showing in perspective any structure. See "Perspective."

Picture Drawing.—A general drawing attempting to show as a picture the actual way the structure would look.

Shop Drawing.—A drawing of a structure or machine showing all parts and dimensions so that the shop can actually build what is indicated on the drawing without other information.

Skeleton Drawing.—Same as "Skeleton Diagram." See "Diagram."

Working Drawing.—Any drawing showing all the parts and dimensions with other information pertinent to construction, so that whatever is shown can be built without other drawings or instructions.

Drawing Down.—Reducing gradually the sectional area.

Draw Plate.—See "Plate."

Draw Rest.—A pile and timber structure, ballasted with rock, built approximately at right angles to the bridge tangent and extending up and down stream so as to underlie the draw span when it is open, thereby affording protection from passing vessels and providing a support for the ends of the span when open. Built sometimes of masonry.

Draw Span.—See "Span."

Dredge.—An apparatus or machine for lifting mud, sand, silt, and small boulders from the bottom of a stream or the bed of an arm of the sea. To excavate with a dredge.

Bucket Dredge.—A dredge which hoists out the material by the use of buckets usually attached to an endless chain.

Clam-shell Dredge.—A dredge using a clam-shell bucket attached to a hoisting apparatus like a derrick.

Dipper Dredge.—A dredge using a dipper or cubical bucket mounted on the end of a boom.

Featherstone Dredge.—One of the many types of dipper dredges.

Ladder Dredge.—A dredge having buckets mounted on an endless, ladder-like chain.

Orange-peel Dredge.—A dredge using an orange-peel bucket attached to a hoisting apparatus like a derrick.

Dredge.

Scoop Dredge.—A dredge provided with one or more scoops

Steam Dredge.—A dredge operated by steam.

Dressed Ashlar.—See "Ashlar."

Dressing.—The sizing, shaping, and facing of stones for masonry work.

Axed Dressing.—A finish in stonework as left by the mason's axe in dressing the face to a plane surface.

Boasted Dressing.—A finish in stonework wrought with a chisel or narrow tool.

Broached Dressing.—A finish in stonework wrought with a "punch" after the surface has been droved.

Broken Axed Dressing.—A stonework dressing made with an axe to resemble "Crandalled Dressing," *q.v.*

Bush Hammered Dressing.—A finish in stonework wrought with a bush hammer.

Chiseled Dressing.—Same as "Boasted Dressing," *q.v.*

Columnar Stroked Dressing.—A droved dressing in masonry in which the flutes are like those in a column.

Crandalled Dressing.—A finish in stonework in which the face of the stone is dressed to a plane with a crandall.

Deadening Dressing.—The crushing or crumbling of soft stone under the tools while being worked, leaving irregularities in the finished surface.

Drafted Dressing.—A finish in stonework having a narrow chisel-draft cut around the face or margin.

Droved Dressing.—A finish in stonework wrought with a broad chisel or hammer in parallel flutings across the face from end to end.

Fibrous Stroked Dressing.—A stroked dressing in masonry in which the flutings are made wavy and like fibres in appearance.

Fine Pointed Dressing.—A type of stone dressing in which the surface left by rough pointing is reduced to a degree of smoothness such that no part projects more than a quarter of an inch beyond the pitch face.

Hammered Dressing.—A finish in stonework wrought with a mason's hammer.

Herring Bone Dressing.—A type of stone dressing made by cutting flutings in a diagonal direction on the face of the stone.

Nidged Dressing or **Nigged Dressing.**—In stonework a finish picked with a pointed hammer or cavil.

Patent Hammered Dressing.—A form of stone facing made with a patent hammer.

Pean Hammer Dressing.—A form of stone facing made with a pean hammer.

Picked Dressing.—A facing of stonework made by a mason's pick in reducing the surface to an approximate plane.

Pitched Dressing or **Pitched Faced Dressing.**—In stonework, a finish dressed to neat lines or edges with a pitching chisel.

Plain Dressing.—In stonework, a facing rubbed smooth to remove tool marks.

Pointed Dressing.—A form of stone facing made by chipping off projections with a mason's point or similar tool.

Polished Dressing.—A finish in stonework made by rubbing a tooled surface down to a reflecting surface.

Prison Dressing.—A type of stone dressing in which the surface is wrought into holes.

Quarry Faced Dressing.—Same as "Rock Faced Dressing," *q.v.*

Random Tooled Dressing.—In stonework a finish cut with a broad tool into irregular flutings.

Rock Faced Dressing.—The facing on stonework left rough as it comes from the quarry. It may be drafted or pitched so as to reduce projecting points on the face or to given limits.

Rock Work Dressing.—Same as "Rustic Dressing," *q.v.*

Dressing.

Rough Dressing.—Same as "Rock Faced Dressing," *q.v.*

Rough Pointed Dressing.—A type of stone dressing which presents an irregular surface, but has no projection exceeding a half inch from the surface of the pitch face.

Rubbed Dressing.—Same as "Plain Dressing," *q.v.*

Rustic Dressing or **Rusticated Dressing.**—A form of stone facing that projects beyond the arrises, which are beveled or drafted. The projecting face may be dressed in any desired form.

Scabbled Dressing.—A form of stone dressing for rubble masonry in which the angular projections of the stones have been dressed off with a stone-axe, or hammer.

Smooth Dressing.—Same as "Plain Dressing," *q.v.*

Square Droved Dressing.—A finish in stonework made by fluting the face perpendicular to the lower edge of the stone.

Striped Dressing.—A dressing in stonework wrought by a mason's point or punch producing parallel grooves.

Stroked Dressing.—Same as "Droved Dressing," *q.v.*

Tooled Dressing.—A dressing in stonework in which the face of the stone is tooled to a plane.

Tooth-axed Dressing.—A form of stonework dressing made with a tooth-axe.

Toothed Dressing.—A type of stone dressing made with a mason's tooth chisel.

Vermiculated Dressing or **Worm Work Dressing.**—A type of stonework finish in which veins are made by cutting away portions of the face.

Drier.—A material containing metallic compounds added to paints and painting materials for the purpose of accelerating the drying.

Drift.—A horizontal or inclined passage in a tunnel. To float away with a current. Débris, such as trees, timbers, brush, etc., carried along by freshets. To match holes in steel work by drift-pins. To swing bridge members into place by means of a double set of ropes and blocks, one set releasing as the other set takes up. To enlarge a hole with a conical pin.

Drift Bolt.—See "Bolt."

Drift Ice.—Masses of detached floating ice which drift with the wind and current.

Drift-pin.—A short, tapered rod for enlarging rivet holes.

Drill.—To bore a hole in a material with a tool revolved by a suitable mechanism. The tool itself or the apparatus holding and turning it.

Calyx Core Drill.—A drill for making borings in earth strata. It consists of a revolving shank having a hollow steel bit under which chilled steel shot are made to travel. The rotation and pressure cause the shot to mill away the rock leaving a portion of it sticking upward inside the drill. At suitable intervals the core is broken off and brought to the surface for examination.

Centre Drill.—A drill for making a central hole, as in a shaft.

Churn Drill.—A steel bar about eight feet long having its ends flattened and sharpened for drilling into hard strata.

Clamp Drill.—A drill having a clamp to hold it to the work.

Core Drill.—A rock drill having a hollow cutter so that as it revolves a core is cut out which extends upward into the interior of the drill bit and shaft. At suitable intervals the core is broken off and brought to the surface for examination.

Countersink Drill.—A tool combining a drill and a countersink in one piece.

Diamond Drill.—A type of core drill using black diamonds set in an annular bit which is revolved by a shaft extending to the ground surface, where it connects with suitable driving machinery.

Double Drill.—A drill with two cutters for making countersunk holes.

Fluted Drill.—A drill having two longitudinal grooves or flutes on opposing sides.

Forked Drill.—A slotted tool with a forked point used in a slot drilling machine.

Drill.

Gang Drill.—A machine tool containing in one head a number of vertical drills, each having its separate belt and pulley operated from a common shaft.

Hand Drill.—Any drill that is operated by hand. Usually one man operating both drill and hammer.

Jumper Drill.—A drill similar to a churn drill only much shorter.

Machine Drill.—A drill mounted in a machine and run by power.

Percussion Drill.—A solid drill-rod having an action like that of a churn drill.

Pin Drill.—A drill for boring pin holes in truss members.

Pneumatic Drill.—Any drill operated by air.

Radial Drill.—A machine rock drill in which the drill tool is fastened to a radial arm.

Ratchet Drill.—Any drill operated by a ratchet mechanism.

Rock Drill.—Any drill used for quarrying rock.

Rose Drill.—A drill with a cylindrical cutting face.

Rotating Drill.—A drill having a rotating motion instead of a churning motion.

Socket Drill.—A drill having a shank that fits into a socket.

Stone Drill.—A bar used to cut holes in stones and rocks.

Straight Shank Drill.—A drill having a straight shank, in contra-distinction to a tapered shank, *q.v.*

Taper Shank Drill.—A drill having a tapered shank.

Teat Drill or **Tit Drill.**—A square-faced cylindrical drill, with a sharp, pyramidal projection issuing from the centre of the cutting face.

Twist Drill.—A cylindrical drill having two parallel, spiral grooves on opposing sides and the point sharpened to an obtuse angle.

Drill Barrow.—Same as "Drill," *q.v.*

Drill-bit.—The cutting tool used in a drilling machine. Also called "Drill," *q.v.*

Drill Chuck.—See "Chuck."

Drill Gauge.—See "Gauge."

Drilling Machine.—A machine for boring holes in metals, rock, etc.

Drillings.—The cuttings, or shavings, arising during the process of drilling. Also the holes that are drilled in the ground.

Drill Plate.—A breast-plate for hand-drilling operations.

Drill Press.—See "Presses."

Drill Scow.—See "Scow."

Drill Stock.—See "Stock."

Drip.—A small channel cut under the lower projecting edge of a coping, etc., so that when rain reaches that point, it will drip or fall off.

Drip Pipe.—See "Pipe."

Drip Stone.—See "Stone."

Driven Pulley.—See "Pulley."

Driver.—One of the large wheels which drive any machine or apparatus.

Locomotive Driver.—One of the large driving wheels of a locomotive. Also the man who operates or drives a locomotive.

Driving Axle.—See "Axle."

Driving Belt.—See "Belt."

Driving Box.—See "Box."

Driving-fit.—In steel work, a fitting for a bolt so tight that the diameter of the hole is practically the same as that of the bolt, which has to be driven in place with a hammer.

Driving Gear.—See "Gear."

Driving Nut.—See "Nut."

Driving Pulley.—See "Pulley."

Driving Shaft.—See "Shaft."

Driving Wheel.—See "Wheel."

Drop.—A contrivance arranged so as to hang, drop, or fall from a higher position to a lower one.

Drop of Beam.—A term used in testing materials to indicate that a test piece has passed the yield point as shown by the sudden dropping of the weighing beam of the testing machine.

Drop Forging.—See "Forging."

Drop Hammer.—See "Hammer."

Drop Hammer Pile Driver.—See "Pile Driver."

Droved Dressing.—See "Dressing."

Drum.—A revolving cylinder around which ropes or belts either travel or are wound. The main portion of a turntable for either locomotives or swing spans.

Friction Drum.—Any drum operated by the action of friction.

Dry Masonry.—See "Masonry."

Dry Puddling.—See "Puddle."

Dry Rot.—See "Rot."

Dry Seam.—See "Seam."

Duchemin's Formula.—A wind pressure formula for surfaces inclined to the direction of the wind,

$$P_n = P \frac{2 \sin A}{1 + \sin^2 A}$$

where

P_n = the normal component of wind pressure,
P = the pressure per square foot on a vertical surface,
A = the angle of inclination of the surface with the horizontal.

Dump.—The place where material such as earth, clay, rock, etc., is deposited. To deposit such material.

Dump Car.—See "Car."

Dump Scow.—See "Scow."

Dumpy Level.—See "Level."

Duplex Hammer.—See "Hammer."

Duplex Slide Rule.—See "Slide Rule."

Durometer.—An apparatus for testing the hardness of steel rails.

Dust Guard.—See "Guard."

Dutch Brick.—See "Brick."

Dutchman.—A wooden block or wedge used to hide an opening in a badly made joint.

Duty.—The number of foot-pounds of work delivered for each hundred pounds of coal burned under a boiler. Also the number of foot-pounds of work delivered for each one thousand pounds of dry steam.

D-Valve.—See "Valve."

Dyke.—Same as "Dike," *q.v.*

Dynamic Deflection.—See "Deflection."

Dynamic Equilibrium.—See "Equilibrium."

Dynamic Horsepower.—Same as "Indicated Horsepower." See "Horsepower."

Dynamics.—That branch of the science of mechanics which treats of the motion of bodies and of the forces acting thereon.

Dynamite.—An explosive of great power, consisting of a mixture of nitroglycerin with some absorbent material such as sawdust. To blow up, destroy, or break up with dynamite.

Dynamo.—A machine for converting mechanical power into electrical power or *vice versa*. In the latter case the machine is called a motor. The essential elements are a field of magnetic flux, produced usually by electro-magnets called field magnets, and a moving set of conductors passing through the magnetic flux so as to cut the lines of force. The moving set of conductors is called the armature.

Dynamometer.—An apparatus for measuring the amount of pull exerted by any machine or engine.

E

Ead's Pump.—See "Pump."

Earth Pressure.—See "Pressure."

Easement Curve.—See "Curve."

Eccentric.—Out of centre. A disk mounted out of centre on a driving shaft and surrounded by a collar or a strap connected with a rod. Its purpose is to convert rotary motion into reciprocating rectilinear motion.

Eccentric Axis.—See "Axis."

Eccentric Gear.—See "Gear."

Eccentricity.—The state or condition of being eccentric. Deviation from a centre.

Economic Depth.—See "Depth."

Economics.—The science of obtaining a desired result with the ultimate minimum expenditure of effort, money, or material.

Eddy.—A whirl or backward current of water. A vortex. That portion of the water in a stream that actually swirls.

Edge.—The sharp margin, or the thin, bordering or terminal line of a cutting instrument. The extreme margin of anything. The brink.

Edger.—A cement finisher's tool for rounding the corners of cement or concrete constructions.

Effective Area.—See "Area."

Effective Depth.—See "Depth."

Effective Horsepower.—See "Horsepower."

Effective Length.—See "Length."

Effective Span.—See "Span."

Efficiency.—The ratio of energy utilized divided by the energy expended.

Efficiency Curve.—See "Curve."

Efflorescence.—A powder-like incrustation formed on bodies such as concrete, metals, etc.

Egg-shell Paper.—See "Paper."

Ejector.—A device for utilizing the momentum of a jet of steam or air under pressure to lift a liquid or a finely divided solid.

Ejector Condenser.—See "Condenser."

Elastic Arch.—See "Arch."

Elastic Curve.—See "Curve."

Elastic Deformation.—See "Deformation."

Elasticity.—That property which many bodies have of recovering their original form after the removal of the deforming cause.

Coefficient of Elasticity or Modulus of Elasticity.—The ratio of the direct stress per unit of area to the corresponding relative deformation, sometimes called Lineal Modulus. The numerical value is equal to the stress per unit of area in tension that would be required to double the length of a piece, were the material of which it is composed perfectly elastic. Also called "Young's Modulus."

Shearing Modulus of Elasticity.—The ratio of the unit shearing stress to the accompanying angular deformation. It generally equals two-fifths of the lineal modulus. See "Modulus of Elasticity."

Volumetric Modulus of Elasticity.—The ratio of the unit stress, applied on the three principal axes, to the relative change in volume. It generally equals two-thirds of the lineal modulus.

Elastic-limit.—The unit stress at which the deformation begins to increase in a faster ratio than the applied loads.

Elbow.—The bend of an arm. The flexure or angle in a wall. A joint in a pipe making a bend. To jut into an angle.
Elbow Joint.—See "Joint."
Electrical Hammer.—See "Hammer."
Electrical Hoist.—See "Hoist."
Electrical Horsepower.—See "Horsepower."
Electrical Locomotive.—See "Locomotive."
Electrical Resistance.—See "Resistance."
Electric Crane.—See "Crane."
Electric Motor.—See "Motor."
Electro-magnet.—A magnet which derives its magnetic properties from the magnetic flux set up by an electric current flowing through its windings.
Element.—That of which anything is in part compounded, which exists in it, and which is itself not decomposable into parts of different kinds.
Truss Element.—A component part of a truss.
Elevation.—The altitude or height above some given line or datum plane; such as sea level, low water, etc. The act of raising. The projection of an object on a vertical plane, used in drafting.
Super-elevation.—The height of the outer rail above that of the inner rail on curved tracks. The rails are thus placed in order to overcome the tendency of a car or train going at high speed to fly off the track. The super-elevation is governed by the speed and degree of curvature.
Elevator.—An apparatus for hoisting loads. A lift. The term often includes the entire hoisting apparatus: *i.e.*, the shaft, cage, and motor.
Hydraulic Elevator.—An elevator operated by some kind of hydraulic mechanism.
Pneumatic Elevator.—A hoisting apparatus operated by compressed air.
Ellipse.—A curve such that the sum of the distances from two fixed points, called the foci, to any point on the curve is a constant.
Ellipse of Stress.—See "Stress."
Elliptical Arch.—See "Arch."
Elliptical Curve.—Same as "Ellipse," *q.v.*
Elongation.—The stretching or extension of a part beyond its natural dimensions.
Embankment.—A bank, a dike, or an earthwork raised for any purpose.
Emerson's Foundation Pump.—See "Pump."
Empirical.—Pertaining to or derived from experience or experiments.
Empirical Coefficient.—See "Coefficient."
Empirical Formula.—See "Formula."
Encased Knot.—See "Knot."
End Floor-beam.—See "Floor-beam."
Endless Chain.—See "Chain."
End-lifting Apparatus.—An apparatus consisting of a toggle, operated by screws, which lifts and latches the ends of a swing span.
End Pin.—See "Pin."
End Post.—See "Post."
End Reaction.—See "Reaction."
End Shear.—See "Shear."
End Stiffeners.—See "Stiffeners."
Energy.—The capability of doing work.
Conservation of Energy.—The doctrine that the sum total of the energy of the universe neither diminishes nor increases, though it may assume different forms successively.
Hydraulic Energy.—The energy of water in motion.
Kinetic Energy.—Energy that is due to motion.
Potential Energy.—Energy that is due to position.

Energy.

Total Energy.—The sum of the kinetic and the potential energies.

Engage.—To bring two pieces into contact. To mesh, as to connect gears.

Engine.—An apparatus or machine for converting some form of energy into mechanical power for the doing of useful work.

Assistant Engine.—A steam or hydraulic motor used to control the reversing gear of a marine engine, or to turn the shaft when the main engine is at rest.

Dinkey Engine.—Same as "Dinkey Locomotive."

Donkey Engine.—A small stationary steam engine attached to a larger one. A subsidiary engine used for hoisting.

Gas Engine.—An internal combustion engine using gas as a fuel.

Gasoline Engine.—An internal combustion engine using gasoline as a fuel.

Hoisting Engine.—An engine used to operate hoists, derricks, pile drivers, etc.

Internal Combustion Engine.—An engine in which the fuel, such as gas, vapor, gasoline, or oil is burned direct in the cylinder, generating a high temperature and high pressure in the gases of combustion, which expand behind a piston and drive it forward.

Jack Engine.—A small engine employed in sinking a shallow shaft, a donkey engine.

Monkey Engine.—A hoisting engine used to raise a pile-driver hammer.

Stationary Engine.—An engine that rests on a fixed foundation and is not movable.

Steam Engine.—An engine in which a portion of the heat energy of the fuel is conveyed to the cylinder by means of steam, which expands behind the piston and drives it forward.

Engineering News Formula.—A formula proposed by the late A. M. Wellington, C.E., for determining the safe load on piles.

$$\text{Safe Load} = \frac{2\,W\,H}{s+1}$$

where

W denotes the weight of the drop or steam hammer;

H denotes the fall in feet or the stroke in a steam hammer;

and

s denotes the average penetration of the pile per blow in inches under the last few blows.

For steam hammer work this formula is modified by substituting 0.1 in place of unity in the denominator.

Engineer's Hammer.—See "Hammer."

Engineer's Level.—See "Level."

Engineer's Scale.—See "Scale."

English Bond.—Same as "Old English Bond." See "Bond."

Enlarged Scale.—See "Scale."

Entasis.—A slight convex curve in the vertical outline of a pilaster or of the shaft of a column.

Epicycloid.—A curve generated by the motion of a point on the circumference of a circle which rolls on the convex side of a fixed circle.

Epicycloidal Tooth.—See "Tooth."

Equalizer.—An adjuster; a leveler. A device for distributing a load equally over several parts.

Equilibrium.—A state of balance produced by the counteraction of two or more forces. The state of a body so acted upon by a balanced system of forces that it has no tendency to change its condition of motion or rest.

Dynamic Equilibrium.—That condition of a body in uniform motion in which the resultant of all the forces acting thereon is zero.

Equilibrium.

Indifferent Equilibrium.—That condition of a body when a slight displacement of it is retained without further motion.

Stable Equilibrium.—That condition of a body when a slight displacement of it is followed by a return to the original position.

Static Equilibrium.—That condition of a body at rest in which the resultant of all the forces acting thereon is zero. There are three types of Static Equilibrium, viz., Stable, Unstable, and Indifferent.

Unstable Equilibrium.—That condition of a body when a slight displacement of it is followed by a further displacement.

Equilibrium of Three Parallel Forces in One Plane.—Same as "Laws of the Lever." See "Lever."

Equilibrium Polygon.—See "Polygon."

Equivalent Uniform Live Load.—See "Load."

Erecting-bill.—A bill of material for a bridge, so arranged as to facilitate the finding and placing of members during erection.

Erection.—The assembling of the members of a bridge in the field and making the necessary permanent connections.

Erection Car.—See "Car."

Erection Diagram.—See "Diagram."

Erection Drawing.—Same as "Erection Diagram." See "Diagram."

Erection Gang.—See "Gang."

Erection Stress.—See "Stress."

Escarpment.—A nearly vertical natural face of rock or soil.

Estimate.—To figure quantities, weights, costs, etc. A statement of such quantities, weights, costs, etc.

Euler's Formula.—A formula expressing the resistance of long columns to buckling, viz.,

$$P = \frac{a\,\pi^2 E I}{l^2}$$

where P = the external load or pressure.
E = the modulus of elasticity.
I = the least moment of inertia.
l = length.
a = constant depending on end conditions.
π = 3.14159.

Even Bearing.—See "Bearing."

Evolute.—A curve which is the locus of the centre of curvature of another curve, or the envelope of the normals to the latter.

Excavating Shaft.—See "Shaft."

Excavation.—The act of taking out material. An open cutting, as in a railway. A hollow or cavity formed by removing the interior substance.

Excavator.—A horsepower or steam-power machine for digging, moving, or transporting earth, loose gravel, sand, or any kind of soil.

Pneumatic Excavator.—An excavator operated by compressed air.

Excentric.—Same as "Eccentric," *q.v.*

Excentric Load.—See "Load."

Excess Load.—See "Load."

Expanding Reamer.—See "Reamer."

Expansion.—Enlargement, lengthening due to heat, or to increase in moisture content.

Coefficient of Expansion.—The amount of expansion per unit of magnitude of the substance, per unit of agent causing the effect. For example: the coefficient of lineal expansion of a bar of steel for an increase in temperature is the expansion per unit of length per degree of temperature.

Expansion Bearing.—See "Bearing."

Expansion Bolt.—See "Bolt."

Expansion-end.—The movable end of a structure, trestle, span, truss, etc.

Expansion Girder.—See "Girder."

Expansion Joint.—See "Joint."

Expansion Pocket.—See "Pocket."

Expansion Roller.—See "Roller."

Explosive.—Pertaining to, or of the nature of, explosion. Any substance by the decomposition of which gas is generated with such great rapidity that an internal pressure is suddenly set up, producing the effect of tremendous impact, and the rupture of the restraining medium.

Extension Bar.—See "Bar."

Extension Plate.—See "Plate."

Extensometer.—An apparatus for measuring minute degrees of expansion or contraction in metal bars under the influence of temperature or under stress.

External Wall.—See "Wall."

Extrados.—The convex curve of a masonry arch. The upper surface of the voussoirs when in position.

Extreme Fibre.—See "Fibre."

Extreme High Water.—See "Water."

Extreme High Water Mark.—See "Water."

Eye.—The hole in the end of a member to permit the passage of a pin.

Bolt Eye.—The eye in an "Eye Bolt," *q.v.*

Loop Eye.—An eye on the end of a rod or square bar elongated in the form of a loop.

Slotted Eye.—An oval eye in the end of an eye-bar in place of the usual round hole.

Eye and Strap.—A hinge which fits over an eye.

Eye-bar.—A bar with an eye at either one end or each end.

Adjustable Eye-bar.—An eye-bar that can be lengthened or shortened after erection by means of a sleeve-nut, turn-buckle, or clevis.

Trussed Eye-bar.—An eye-bar supported by trussing so as to resist compression or bending.

Eye-bar Dog.—See "Dog."

Eye-bar Head.—See "Head."

Eye-bar Hook.—See "Hook."

Eye-bar Upsetter.—A machine for enlarging the end of a plain bar sufficiently to permit the forming of an eye that will develop the full strength of the bar.

Eye Bolt.—See "Bolt."

Eye-piece.—The lens in the small end of a transit or level.

Eye Splice.—See "Splice."

F

Fabrication.—The act or process of framing and fitting rolled steel shapes for structures. The putting together of parts of a structural steel construction and riveting them.

Façade.—An elevation or exterior face of a building, usually the front or chief face.

Face.—A plane, exterior face of a solid. The front view or exposed part. The working or cutting portion of a grinding-wheel, or the edge of any cutting tool. To prepare or polish a face.

Faced Joint.—See "Joint."

Face of Gear Tooth.—See "Tooth."

Face Wall.—See "Wall."

Facing.—A layer of earth, turf, or stone laid upon the sloping sides of a railroad embankment or other inclined earthwork in order to protect the exposed surface and to give it a steeper slope than generally is natural.

Facing Brick.—See "Brick."

Factor.—One of the two or more numbers, expressions, or quantities which multiplied together form a given product.

Factor of Safety.—Same as "Safety Factor," *q.v.*

Fall Blocks.—See "Block."

Fall Line.—See "Line."

Fall Line Ball.—A heavy iron ball with two projecting staples for attaching to the movable block of a hoisting tackle to overhaul the lines when no load is carried.

Falls.—The ropes used with pulley blocks in hoisting.

False-bottom.—A movable, horizontal partition inserted in the lower part of a box, shell, bucket, etc.

False Cap.—See "Cap."

Falsework.—The scaffold or temporary supports employed for erecting a structure. Usually a temporary timber trestle sustaining a bridge during erection.

Flying Falsework.—A type of falsework used in the erection of large cantilever bridges. It consists of a horizontal truss, lying in the plane of the lower chord, with a set of heavy girders under each of its own chords in order to furnish a bearing for the jacks to work against. Each side of its flying end is hung by two ties, consisting of eye-bars, which are in turn attached to the last sub-panel point erected. The rear end of this flying falsework is supported by the pier for the first panel erected and then by the last bottom chord panel point for succeeding panels.

Lower Falsework.—The falsework built below the level of the bottom chords.

Upper Falsework.—The falsework above the elevation of the bottom chords. It is no longer used in erection, as its object is more readily accomplished by the traveler, which apparatus has replaced it entirely.

Falsework Bolts.—Any bolts used in tying wooden bracing to posts or piles.

Falsework Cap.—See "Cap."

Falsework Pile.—See "Pile."

Fan-tail Joint.—See "Joint."

Fascia.—Any flat member or moulding with but little projection, usually the outermost portion.

Fascia Girder.—See "Girder."

Fascine.—A bundle of brush wired together and used in the construction of river protection work to prevent the washing away of the banks. Similar to "Babies," *q.v.*

Fastening Angle.—Same as "Connecting Angle." See "Angle."

Fast Joint.—See "Joint."

Fast Pulley.—See "Pulley."

Fat Lime.—See "Lime."

Fatigue of Metal.—See "Metal."

Faucet.—A device fixed in a receptacle or pipe to control the flow of liquid.

Feather.—A longitudinal, projecting guide on a shaft. One of the two tapered pieces of metal placed in a hole in conjunction with a plug, used for splitting rock.

Plug and Feathers.—A combination of two feathers and a tapering plug inserted in a hole in a rock, the plug being driven with a hammer so that great lateral pressure is produced and the rock broken.

Feather and Wedge.—A single feather combined with a wedge, used in quarries for splitting rock.

Feather-edge.—Any edge that is thin and sharp like a feather. The edge of a board that is thinner than the other.

Feather-edge Brick.—See "Brick."

Featherstone Dredge.—See "Dredge."

Feed Water Pump.—Same as "Donkey Pump." See "Pump."

Felloe.—The circular rim of a wheel into which the outer ends of the spokes fit.
Felloe Plank.—See "Plank."
Felly.—Same as "Felloe," *q.v.*
Felly Plank.—Same as "Felloe Plank." See "Plank."
Felt.—An unwoven fabric of short hair or wool matted together by rolling. Used for waterproofing by applying pitch.
Female Joint.—See "Joint."
Female Screw.—See "Screw."
Fender.—A guard for protection. Vertical timbers, piles, etc., to protect vessels from striking, rubbing, and scarring piers.
Fender Pile.—See "Pile."
Fiber or **Fibre.**—The longitudinal filament of a body.
Extreme Fibre.—The fibre which is most remote from the neutral axis.
Indurated Fibre.—A hard, thick, dense, fibrous material used for insulation in electrical apparatus.
Vulcanized Fibre.—A vegetable fibre saturated and coated with a metallic chloride giving the material toughness and strength.
Fibre Stress.—See "Stress."
Fibrous.—Containing or consisting of fibres.
Fibrous Fracture.—See "Fracture."
Fibrous Iron.—See "Iron."
Field-book.—A book containing any field records.
Field Rivet.—See "Rivet."
Field Work.—See "Work."
Fiery.—The character or quality of steel as exhibited by its fracture when the grains are very coarse and bright.
Fiery Steel.—See "Steel."
Figure-eight Knot.—See "Knot."
File.—A collection of papers arranged in order. A receptacle for holding papers. A rough steel hand-tool used for reducing or smoothing metals, wood, and other resistant materials. To cut or wear away a portion of an object by the application of a filing tool.
Bastard File.—A file having an intermediate surface between that of a smooth and a rough file.
Blunt File.—A file terminating in a blunt end.
Circular File.—A small file having a circular cross section.
Double End File.—A file having both ends cut for service.
Flat File.—A thin file flat on the two opposite faces.
Flat Wood File.—A coarse-cut, flat file for using on wood.
Half-round Bastard File.—A medium cut file having a semi-circular cross section.
Half-round Wood File.—Similar to a half-round bastard file, excepting that it is coarser cut and is used exclusively on wood.
Joint File.—A small round file of uniform section throughout its length.
Rat-tail File.—A small, circular, tapering file which resembles a rat's tail.
Square File.—Any file having a square cross section.
Taper File.—A file having a tapering body.
Triangular File.—Any file having a triangular cross section.
Fill.—To occupy with material so as to leave no space empty. An embankment behind an abutment. Any railroad embankment.
Filler.—A plate the sole function of which is to fill up space. Anything that serves to fill up a vacancy.
Pin Filler.—A ring placed on a pin between connecting members to keep them in position.
Filler Plate.—See "Plate."

Fillet.—A plain, narrow, flat moulding in a cornice or a corner. The rounding of a sharp corner.

Filling.—The material in an embankment or that put back into an excavation.

Back-filling.—Material put back into an excavation around a pier, pedestal, or abutment.

Filling Pile.—See "Pile."

Fin.—A thin projection on a surface of a casting caused by the imperfect contact of the two moulding flasks each containing a part of the mould. A small, thin projection on the rolled surface of any metal, especially at the edges thereof.

Final Set.—See "Set."

Final Set of Cement.—See "Set."

Fineness.—The relative size of the particles of cement, sand, or other materials.

Fine-pointed Dressing.—See "Dressing."

Fine Sand.—See "Sand."

Finish.—The condition of a surface after the final work upon it has been performed. To complete anything.

Cement Finish.—A finish made by using a cement coating.

Float Finish.—A finish on cement work made by floating grout over the surface with a straight edge.

Ground Finish.—A finish made on an object by grinding.

Indented Finish.—A finish made on cement work by running an indentation roller over it while soft.

Machine Finish.—A finish on metalwork made by turning in a lathe or planing in a machine.

Planed Finish.—A finish produced by planing.

Rough Finish.—The finish which is left by the original forms, moulds, etc.

Troweled Finish.—A finish on cement work made by troweling.

Finishing Stake.—See "Stake."

Fink Truss.—See "Truss."

Fire Brick.—See "Brick."

Fireless Locomotive.—See "Locomotive."

First-class Masonry.—See "Masonry."

First Cost.—See "Cost."

Fish.—To join two beams by fastening long splice-pieces to their sides.

Fish-bellied Girder.—See "Girder."

Fish-belly.—The form taken by some girders or trusses where the bottom flange or chord is convex downward. To swell downward.

Fishbolt.—See "Bolt."

Fisherman's Bend.—A knot. See "Knot."

Fishing.—The act of uniting two parts by clamping them between two short pieces which cover the joint.

Fish Joint.—See "Joint."

Fish Plate.—Same as "Splice Bar." See "Bar."

Fitting-up.—Assembling the different members of a structure and connecting them with bolts preparatory to riveting.

Fitting-up Bolt.—See "Bolt."

Fitting-up Clamp.—See "Clamp."

Fitting-up Gang.—See "Gang."

Fixed Bridge.—See "Bridge."

Fixed Charges.—The annual expenditure, in connection with a structure, which remains the same, or nearly so, regardless of operation. Generally refers to the interest on the bonded indebtedness.

Fixed End.—The anchored end. An end of a girder or strut so firmly connected as to prevent all motion in the vicinity of the end.

Fixed Load.—See "Load."

Fixed Point.—Any point that is stationary or assumed to remain fixed throughout the entire discussion. The common centre of gravity of a system of bodies.

Fixed Post.—See "Post."

Fixed Span.—See "Span."

Flange.—One of the principal longitudinal members of a girder which resist tension or compression, also sometimes called the upper and lower chords of a beam. A projecting edge, rim, or rib on anything.

Wheel Flange.—The lip or projection on the face of a wheel acting as a guide or restraint.

Flange Angles.—See "Angle."

Flange Coupling.—See "Coupling."

Flange Joint.—See "Joint."

Flange Plate.—See "Plate."

Flange Rail.—See "Rail."

Flange Splice.—See "Splice."

Flange Stress.—See "Stress."

Flange Union.—See "Union."

Flank (of gear tooth).—See "Tooth."

Flap Valve.—Same as "Check Valve." See "Valve."

Flashing Angle.—See "Angle."

Flashing Point.—The temperature at which escaping gas will ignite momentarily.

Flashings.—Broad strips of sheet metal used at the joints of a wall so as to lap over gutters, chimneys, etc. Also strips worked in under the slates or shingles around dormers, chimneys, and any rising part, to prevent leaking.

Flasks.—The upper and lower parts of a box which contain the mould into which molten metal is poured.

Flat.—The broad side of anything. Any rectangular iron or steel bar having a greater width than thickness. A level stretch of ground near a stream.

Flat Arch.—See "Arch."

Flat Dolly.—See "Dolly."

Flat File.—See "File."

Flat-head.—A rivet or bolt head that has been flattened.

Flat-head Rivet.—See "Rivet."

Flat Rasp.—See "Rasp."

Flat Reamer.—See "Reamer."

Flat Rope Pulley.—See "Pulley."

Flat Scale.—See "Scale."

Flattening.—Causing painting to have a dead or dull finish instead of a glossy one by using turpentine instead of oil in the last coat.

Flat Wood File.—See "File."

Fleet.—To swing into place by means of a horizontal, subsidiary tackle, a bridge member when it has to be picked up by the main tackle from a position not directly under the support of the main tackle.

Fleeting Tackle.—See "Tackle."

Flemish Bond.—See "Bond."

Flemish Brick.—See "Brick."

Flemish Knot.—See "Knot."

Flemish Loop.—See "Knot."

Flexible Joint.—See "Joint."

Flexure.—Bending.

Common Theory of Flexure.—The theory accounting for the stress intensity and distribution in a beam subjected to transverse loading on the assumptions that the flexure is slight, that the elastic limit is not exceeded in any part of the beam,

Flexure.

that all plane normal sections remain plane after bending, and that the intensity of either tensile or compressive stress in any normal section acting parallel to the axis of the beam varies directly as the distance from the neutral axis.

Fliers.—A straight flight of steps in a stairway.

Flight.—A continuous series of steps connecting two different levels.

Flitch.—A plank or slab, especially one of several planks fastened side by side to form a compound beam. To join planks in order to make such a beam.

Flitched Beam.—See "Beam."

Flitched Girder.—Same as "Sandwich Girder." See "Girder."

Flitched Plate.—See "Plate."

Floated Surface.—A surface made on cement or concrete work while wet by rubbing with a smooth board.

Floater.—A term used for a bridgeman who works a few days on one job and then moves to another.

Float Finish.—See "Finish."

Floating Bridge.—Same as a "Boat Bridge" or a "Pontoon Bridge." See "Bridge."

Floating Derrick.—See "Derrick."

Floating Pile Driver.—See "Pile Driver."

Flogging Hammer.—See "Hammer."

Floor or Flooring.—That part of a bridge which directly receives the travel.

Ballasted Floor.—A bridge floor under a railway track upon which ballast is placed with ties embedded therein.

Buckle Plate Floor.—In bridgework a floor system that is composed of buckle plates for supporting pavement.

Cement Floor.—A floor having a grouted wearing surface.

Concrete Floor.—A floor made of concrete.

Corrugated Steel Floor.—A floor system composed of corrugated steel.

Reinforced Concrete Floor.—A floor composed of reinforced concrete slabs.

Solid Steel Floor.—A floor composed of steel beams and steel plates, such as flat, buckled, or trough plates.

Suspended Floor.—A floor attached to suspension cables or to girders by hangers.

Tile Floor.—A floor laid with tile.

Timber Floor.—A floor consisting of timber joists and planks.

Trough Plate Floor.—A bridge floor system composed of trough plates.

Wearing Floor.—A floor exposed to the traffic. Usually refers to the upper layer of a double plank floor.

Floor-beam.—A transverse beam or girder placed at the panel points of a span to support the stringers which carry the floor.

End Floor-beam.—The floor-beam at the end of a span.

Intermediate Floor-beam.—Any floor-beam between the end floor beams.

Floor-beam Concentration.—See "Concentration."

Floor Bolt.—See "Bolt."

Floor Girder.—See "Girder."

Flooring.—Same as "Floor," *q.v.* Also planks used in floors.

Dressed and Matched Flooring.—Planks that are dressed on both sides and matched, *i.e.*, tongued and grooved.

Floor Plank.—See "Plank."

Floor Space.—The area of a floor.

Floor Spike.—See "Spike."

Floor System.—The system of members in a bridge that carries the floor and its load.

Flour of Lime.—See "Lime."

Flow (of liquids).—A continuous passing of a liquid. A current.

Flow (of solids).—The permanent change in relative position of the elements of a solid subjected to great pressure.

Flume.—A moderate-size ditch or channel for conducting water.

Flush.—To make one part even or level with another. To wash by turning on a sudden dash of water.

Flush (with mortar).—Same as to float, *q.v.* Also to throw rich grout onto old concrete before pouring new concrete on.

Flush Joint.—See "Joint."

Fluted.—Grooved or furrowed.

Fluted Drill.—See "Drill."

Fluted Reamer.—See "Reamer."

Fluting.—The system of longitudinal grooves in a pilaster or column.

Flux.—To convert to a liquid state by means of heat; to melt. A substance that promotes the fusion of minerals or metals. The process of melting. Fusion.

Flying Buttress.—See "Buttress."

Flying Falsework.—See "Falsework."

Flying Level.—See "Level."

Fly Wheel.—See "Wheel."

Folding Bridge.—Same as "Jack-knife Bridge." See "Bridge."

Foliated Granite.—See "Granite."

Follower.—Any cog that is driven by another. A temporary piece of pile or timber set above a pile that is to be driven below the leads of the pile-driver.

Foot Block.—See "Block."

Foot Bridge.—See "Bridge."

Foot Hammer.—See "Hammer."

Footing.—The spreading course at the base of a foundation.

Column Footing.—A footing, or spread base, under a column.

Pier Footing.—A footing under a pier.

Footing Beam.—See "Beam."

Footing Course.—See "Course."

Foot-pound.—A unit of work equal to that involved by the raising of a weight of one pound one foot high. Also used as a unit of bending moment in which case it is equal to a force of one pound multiplied by a lever arm of one foot. This latter unit is called by some authorities "pound-foot," *q.v.*

Foot-pound Second.—A unit of power, or rate of doing work, equal to raising one pound one foot high in one second.

Foot-ton.—See "Ton."

Foot-walk.—A sidewalk for pedestrians.

Force.—That which moves or tends to move matter. The action between two bodies either causing or tending to cause change in their relative rest or motion.

Centrifugal Force.—The reaction of a body, due to its inertia, against that force which is causing it to deviate from a straight-line motion and to travel in a curved path. A fictitious force apparently balancing the central force.

Centripetal Force.—A force pulling a body toward the centre of rotation.

Concurrent Forces.—Forces in which the lines of action intersect in a common point.

Impulsive Force.—A force which produces a finite change of motion in an indefinitely brief time.

Internal Force.—Same as "Internal Stress." See "Stress.'

Parallelogram of Forces.—See "Parallelogram of Forces"

Resultant Force—Same as "Resultant," *q.v.*

Force Diagram.—See "Diagram."

Force Polygon.—See "Polygon."

Force Pump.—See "Pump."

Force Triangle.—See "Triangle."

Foreman.—A man who directs the work either in person or through his sub-foremen.

Day Foreman.—A foreman who directs the day shift of workmen.

General Foreman.—A man in charge of all construction work, but who generally has no part in the administration of the business.

Night Foreman.—A foreman who directs the work of a night shift.

Sub-foreman.—A foreman under the general foreman who is in charge of more than one gang of men.

Foresight.—A forward observation made with a surveyor's instrument. A fixed object in the front which is sighted upon from time to time to check the orientation of the instrument.

Forge.—To work wrought iron into shape by first softening by heat and then hammering into required form. The apparatus or furnace in which the iron is heated before being worked.

Blacksmith's Forge.—A small forge used by a blacksmith.

Rivet Forge.—A small forge used for heating rivets.

Forge Hammer.—See "Hammer."

Forge Iron.—See "Iron."

Forge Pig.—See "Pig."

Forge Shop.—A shop in which forgings are made.

Forging.—The process of welding metal or that of bringing it to shape when hot by hammering. Also the article made by a forging process.

Drop Forging.—A forging produced by a drop press.

Forked Drill.—See "Drill."

Forked-end.—The end of a bar, wrench, truss member, etc. which is separated into two or more projecting parts like the tines of a fork.

Forked Wrench.—See "Wrench."

Form.—A shape or mould. A figure described by lines and surfaces. A temporary wooden or metallic structure for giving concrete a desired shape.

Former.—A device for giving a particular shape to an article.

Forming Iron.—A blacksmith's swage block.

Formula.—Any general equation; a rule or principle expressed in algebraic symbols.

Empirical Formula.—A formula pertaining to or derived from experience or experiments.

Rational Formula.—A formula derived from fundamental principles.

Straight-line Formula.—One of the several types of formulæ used to express the resistance of columns. In this type the relation of the strength of the column to its length divided by its least radius of gyration can be represented by a straight line.

Foundation.—That portion of a structure, usually below the surface of the ground, which distributes the pressure upon its support. Also applied to the supporting material itself.

Pile Foundation.—A foundation formed in soft soil by driving a group of piles to a depth which will give them the requisite bearing capacity to carry the load.

Spread Foundation.—Similar to "Footing," *q.v.* Also the spread portion below steel cylinders for piers; the spreading being done after the cylinders are sunk to place.

Foundation Bed.—See "Bed."

Foundation Pile.—See "Pile."

Foundation Pit.—See "Pit."

Foundry.—An establishment or plant where metals are cast.

Iron Foundry.—The place where iron castings are made.

Fox Bolt.—See "Bolt."

Foxtail.—A thin wedge inserted into a slit at the lower end of a pin so that when the pin is driven down the wedge enters it and causes it to spread and thus hold more firmly.

Fracture.—To break or split. A partial or total separation of parts of a continuous solid body under the action of force.

Angular Fracture.—A sharp-pointed or sharp-cornered fracture.

Columnar Fracture.—A cleavage into columns shown in the surfaces of the fracture.

Conchoidal Fracture.—A fracture showing shell-shaped depressions.

Crystalline Fracture.—A fracture leaving small crystals showing.

Cup Fracture.—A fracture in the shape of a cup.

Fibrous Fracture.—A fracture that shows the broken ends of fibres.

Granular Fracture.—A fracture showing grains or granules on its surface.

Irregular Fracture.—An extremely uneven fracture.

Silky Fracture.—A fracture showing a glossy surface.

Smooth Fracture.—A fracture either without any projections or having very few of them.

Fracture Section.—See "Section."

Frame.—The sustaining parts of a structure. Framework. An instrument for holding or supporting things, as the frame of a hack-saw.

Bed Frame.—The frame on which the bed of an engine rests.

Cross Frame.—A transverse bracing frame between stringers. Also termed a "Buck Brace."

Hand Frame.—An iron barrow used in a foundry.

Printing Frame.—A frame with a padded cloth back and a glass front, used in the process of making blue prints.

Roller Frame.—Same as "Roller Box." See "Box."

Wheel Frame.—A framework supporting a wheel or wheels.

Framed Bent.—See "Bent."

Framed Bridge.—See "Bridge."

Framed Girders.—See "Girders."

Frame Diagram.—See "Diagram."

Framed Trestle.—See "Trestle."

Frame Pulley.—See "Pulley."

Framework.—An open structure supporting anything.

Framing.—The cutting and shaping of timbers which fit together to form a framework.

Framing Chisel.—See "Chisel."

Free-body Method.—A method that consists in conceiving a body or a portion thereof as isolated from all others which act in any way upon it, those actions being introduced as so many forces, known or unknown, in amount and position.

Free-end.—The expansion end, or the end that is free to move or to rotate.

Free Lime.—See "Lime."

Freezing Process.—A process for freezing earth that is thoroughly saturated with water, by means of a freezing mixture forced into tubes by an ice-making machine. When the wall of earth is frozen sufficiently to withstand the external pressure, the excavation then can proceed as in dry ground.

Freight Locomotive.—See "Locomotive."

Friction.—The resistance to the relative motion sliding or rolling, of surfaces of bodies in contact.

Angle of Friction.—Same as "Angle of Repose," *q.v.*

Coefficient of Friction.—A numerical quantity equal to the ratio of the frictional resistance to the normal pressure between the bodies; or, in other words, to the tangent of the angle of repose.

Journal Friction.—The resistance to rotation offered by the surface of the bearing to the revolving axle or journal.

Rolling Friction.—The resistance offered by a surface to another surface rolling over it.

Friction.

Skin Friction.—The friction between the outer surface of a pile or caisson and the surrounding materials.

Sliding Friction.—The resistance offered by a surface to another surface sliding over it.

Work Done in Overcoming Friction.—See "Work."

Work of Friction.—Used loosely for "Work Spent in Friction," *q.v.*

Frictional Gearing.—See "Gearing."

Friction Brake.—Same as "Prony Friction Brake." See "Brake."

Friction Clutch.—See "Clutch."

Friction Coupling.—See "Coupling."

Friction Drum.—See "Drum."

Friction Gear.—See "Gear."

Friction Hammer.—See "Hammer."

Friction Pulley.—See "Pulley."

Friction Roller.—See "Roller."

Friction Washer.—See "Washer."

Friction Wheel.—A form of slip coupling applied in cases where the variations in load are sudden and great, as in dredges.

Frieze.—The middle division of an entablature; that part above the architrave, and below the cornice.

Frog.—A contrivance built of four pieces of rails mounted on a common base and used for passing the flanges of car-wheels across a rail of an intersecting track.

Frost Batter.—See "Batter."

Frustum.—That which is left of a solid, usually a cone or pyramid, after cutting off the upper part, including the vertex, by a plane that is generally parallel to the base.

Fulcrum.—A pivot point or support. The point about which a lever turns.

Fuller.—A special block with a rounding edge set into an anvil for bending heated metals.

Full Splice.—See "Splice."

Function.—A mathematical quantity which has a value depending upon the values of other quantities that are called the arguments, or independent variables, of the function.

Trigonometric Functions.—Certain functions of an angle or arc used in trigonometry, such as sine, cosine, tangent, or their several reciprocals.

Funicular Polygon.—Same as "Equilibrium Polygon." See "Polygon."

Furnace.—A structure in which a fire is maintained to heat materials or to melt metals or ores.

Acid Open-hearth Furnace.—A furnace used in the manufacture of Acid Open-hearth Steel. See "Steel."

Annealing Furnace.—A furnace in which the process of annealing is carried on.

Asphalt Furnace.—A portable furnace in which asphalt cement is heated for use in roofing or paving.

Assay Furnace.—A small, simple form of furnace and muffler for heating metals in cupels.

Balling Furnace.—A furnace in which the fagots of metal are placed to be heated, preparatory to working.

Basic Open-hearth Furnace.—A furnace used in the manufacture of Basic Open-hearth Steel. See "Steel."

Bessemer Furnace.—A furnace mounted on trunnions so as to be tilted in either direction and having air-blast connections through the trunnions, used for converting pig iron into Bessemer steel by a process of decarburization.

Blast Furnace.—A furnace used in smelting iron ore.

Furnace.

Cementing Furnace.—A furnace used in the process of cementation. See "Cementation."

Iron Furnace.—A general term for any iron working furnace, such as a blast furnace, puddling furnace, etc.

Open-hearth Furnace.—In steel manufacture, a regenerative, reverberatory furnace in which the hearth is exposed to the action of the flame.

Puddling Furnace.—A reverberatory furnace in which cast iron is converted into wrought iron.

Regenerative Furnace.—An open-hearth furnace using producer gas as a fuel, but so arranged that the gas is conducted to the hearth area through a passage-way filled with red-hot bricks stacked to form an open checkerwork. As the hot gas enters the furnace, it is mingled, in proper proportions, with air similarly heated; so that complete combustion is produced. The escaping hot gases are conducted through a second passage-way filled with bricks, which absorb much of the waste heat. The two passage-ways are used alternately to heat the producer gas as it is fed into the furnace.

Reverberatory Furnace.—A furnace having a vaulted ceiling which deflects the flames and heat toward the hearth where the ore is to be fused, the fuel being separated from the ore by a compartment.

Rotary Furnace.—A form of puddling furnace in which the hearth is made to rotate in a vertical or a horizontal plane in order to assist in removing the carbon.

Furring.—A piece placed upon another that is too low, merely to bring its upper surface to a required level.

Fuse.—To melt. A slow burning match used to ignite an explosive, such as powder or dynamite. By burning some time it enables the man lighting the fuse to get out of the way before the explosion occurs.

Percussion Fuse.—A detonating fuse which is exploded by impact.

Fuze.—Same as "Fuse," *q.v.*

G

Gad.—The sharp point on a steel rod, spear, pike pole, or stake.

Gadding.—In quarrying, the drilling of holes for taking out dimension stone

Gadding-machine.—The drilling machine used in gadding.

Gad Steel.—See "Steel."

Gaff.—A steel or iron hook without a barb, provided with a wooden handle, used to haul in objects that have fallen overboard from a vessel. To hook or engage with a gaff.

Gaff Hook.—Same as "Gaff."

Gage.—Same as "Gauge," *q.v.*

Gagger.—A moulder's tool, used to lift sand from a flask in moulding.

Gag Press.—See "Press."

Gag Process.—The process of bending structural shapes in a gag press.

Gain.—A beveled shoulder on the end of a mortised brace for the purpose of giving additional resistance to the shoulder. To make progress. To make grooves or mortises in timber.

Gaining.—The act of cutting grooves or mortises in timbers.

Gaining Machine.—An apparatus that does gaining.

Gallon.—An English unit of capacity for dry or liquid measure containing 231 cubic inches.

Gallows.—A set of timbers consisting of two upright posts, or props, and a bar or cap, laid across their tops and cantilevered out from the posts. Its function is the supporting of objects—generally temporarily.

Gallows-frame.—The frame of a "Gallows," *q.v.*

Galvanized Iron.—See "Iron."

Galvanometer.—An instrument for determining the strength and direction of electric currents.

Gang.—A combination of several tools, machines, etc., operated by a single force, or so contrived as to be made to act as one. Also a company or crew of men.

Bull Gang.—A crew of unskilled laborers for moving steel from the store yards to the bridge site.

Butty Gang.—A gang of workmen who take a contract for a part of any job.

Erection Gang.—A gang that does the work of erection.

Fitting-up Gang.—A gang which does the bolting up of the metal in a bridge shop.

Riveting Gang.—A gang that does the riveting.

Gang Drill.—See "Drill."

Gang Plank.—See "Plank."

Gang Punch.—See "Punch."

Gangway.—A temporary passage used during erection.

Gantry or Gauntry.—A frame or scaffold which supports a crane or other structure.

Gantry Crane.—See "Crane."

Gantry Traveler.—See "Traveler."

Gas Engine.—See "Engine."

Gasket.—Rope-yarn, hemp, rubber, rainbow packing, or sheet lead, used at joints in water pipes and steam pipes, in pistons of steam engines, manholes of boilers, etc., to obtain a tight joint.

Gasoline Engine.—See "Engine."

Gas Pipe.—See "Pipe."

Gate.—A movable barrier. In casting, one of the various forms of openings made in the sand for the molten metal to flow through to the mould. The waste piece of metal cast in the gate. A ridge in a casting which has to be sawn off.

Automatic Gate.—In bridgework, a steel, timber, or concrete gate that works automatically.

Gate Block.—Same as "Snatch Block." See "Block."

Gate Valve.—See "Valve."

Gauge or Gage.—A standard of measure. An instrument for determining dimensions, capacity, quantities, or forces. A standard of comparison. The distance between rivet lines in structural shapes. The distance between the inside faces of the heads of the rails in a track.

Air Gauge.—A dial on an air machine which records at all times the air pressure, usually in pounds per square inch.

Drill Gauge.—A gauge for determining the angle of a twist drill bevel.

Hand Gauge.—The ordinary wooden scratch gauge used by carpenters for marking off a line parallel to the edge of a board.

Hydraulic Gauge.—Same as "Hydraulic Indicator." See "Indicator."

Micrometer Gauge.—Same as "Micrometer Calipers." See "Calipers."

Plate Gauge.—An instrument for measuring the thickness of metal plates.

Pressure Gauge.—A gauge which indicates the pressure of a fluid.

Standard Gauge.—The adopted standard distance between the inner faces of the balls of rails in a track; equal to four feet eight and one-half inches. This was established by agreement between all of the railroads so as to interchange cars.

Steam Gauge.—An instrument for determining and indicating the pressure of steam.

Tide Gauge.—A device for indicating, and in some cases registering, the height of the tide at any time.

Track Gauge.—The distance between the treads of the rails. Also the tool or device for measuring or laying off that distance.

Wire Gauge.—A tool for measuring the diameters of wires or the thicknesses of sheet metals, also the system of sizes and numbers for wires and metal sheets.

Gauge Glass.—The exposed glass tube, connected with a boiler, which shows the height of water in the said boiler.

Gauge Length.—See "Length."

Gauge Pile.—See "Pile."

Gauging.—Making measurements. The act of judging distances, heights, etc., either by eye or by instruments. Ascertaining the volume of discharge of a stream.

Gauntry.—Same as "Gantry," *q.v.*

Gear.—A wheel having teeth on its periphery or face. A piece of mechanism for transmitting motion. To fit with gears. To connect one part of a mechanism at will with another.

Bevel Gears.—Gears having teeth arranged around the convex surface of a conical wheel in the direction of a radial plane passing through the axis of the cone.

Cast Gears.—Gears made by casting and not cut.

Chain Gear.—A device for the transmission of motion by means of a chain engaging the cogs or sprockets of a wheel.

Conical Gear.—Same as "Bevel Gear," *q.v.*

Cut Gears.—Gears in which the teeth are cut by a machine so as to mesh accurately, in contra-distinction to cast gears in which the teeth are not machined.

Differential Gears.—A combination of gears by which a differential motion is produced.

Driving Gears.—Those gears which drive other gears or mechanisms.

Eccentric Gear.—A gear wheel mounted with shaft out of centre.

Friction Gear.—A toothless gear wheel transmitting power by means of friction between its periphery and that of the wheel in contact.

Hand Gear.—A hand mechanism for opening the valves of a steam engine in starting it.

Idle Gear.—An intermediate gear wheel running loosely on its own axle, used to convey motion from one wheel to another, all three being upon different axles.

Knuckle Gear.—A crude form of toothed gearing used for slow-moving machinery, such as cranes.

Locking Gear.—A mechanism which locks a movable span when closed.

Miter Gears.—A pair of beveled gears in which an element of the conical pitch surface makes an angle of forty-five degrees with the axis.

Moulded Gears.—Same as "Cast Gears," *q.v.*

Ratchet Gear.—A gear wheel having sharp-pointed teeth, non-symmetrical about a radial line, leaning away from the direction of rotation so as to engage a pawl which catches on the tooth and prevents backward motion.

Spin Gear.—Same as "Idle Gear," *q.v.*

Spiral Gear.—A gear having teeth arranged spirally, so as to mesh with a worm.

Split Gear.—A gear wheel made in halves for convenience in mounting.

Spur Gear.—A gear having teeth arranged around either the concave or convex surface of a cylindrical wheel and in the direction of a radial plane passing through the axis.

Stepped Gear.—A form of gearing in which each tooth or cog on the face of a wheel is replaced by a series of smaller teeth.

Stripping of Gears.—The tearing or shearing off of the teeth of gear wheels or portions thereof.

Worm Gear.—A gear wheel having special oblique teeth which mesh with a worm.

Geared Locomotive.—See "Locomotive."

Gearing.—A train of gear wheels. A general term for the parts of a machine or mechanism, taken collectively, which transmit motion.

Frictional Gearing.—Wheels which make rolling contact and transmit motion by the friction set up between their surfaces.

Gearing.

Knuckle Gearing.—A train of knuckle gears, *q.v.*

Meshing of Gearing.—The engaging or interlocking of the teeth of one gear with those of another.

Pivot Gearing.—A system of gearing so divided as to admit of shifting the axis of the drive so that the machine can be set in any direction with relation to the power.

Gear Wheel.—A wheel having teeth that will mesh with those of another toothed wheel or with a toothed rack. Also called "Gear," *q.v.*

General Contractor.—See "Contractor."

General Drawing.—See "Drawing."

General Foreman.—See "Foreman."

General Layout.—See "Layout."

Geometrical Progression.—See "Progression."

Geostatic.—Pertaining to earth in a quiescent condition due to a balance of forces or pressures. Having the quality of maintaining earth in equilibrium.

Geostatic Arch.—See "Arch."

German's Knot.—Same as a "Figure Eight Knot." See "Knot."

German Steel.—See "Steel."

Giasticutus Rod.—See "Rod."

Gib.—A piece of metal in the shape of an elongated channel, used as a clamp.

Gilbreth Pile.—See "Pile."

Gin.—A revolving vertical pole or column, usually furnished with a rope drum, having one or more long horizontal arms by which power is applied to turn the drum and wind up the rope, thereby raising a weight.

Horse Gin.—A gin driven by one or more horses.

Gin Block.—See "Block."

Gin Pole.—A mast, or vertical pole, guyed to the ground by cables. Used in connection with blocks and tackle for raising weights.

Gin Pole Derrick.—See "Derrick."

Gin Tackle.—See "Tackle."

Gin Type Derrick.—See "Derrick."

Girder.—A beam or compound structure acting as a beam carrying principally transverse loads which develop normal reactions at the supports.

Arched Girder.—A girder which is cut, bent, or built in the shape of an arch.

Bowstring Girder.—A girder consisting of a curved rib or beam, having a horizontal tension member arranged as a chord and connected to the rib by vertical tie rods.

Box Girder.—A type of girder having two webs giving a section resembling a box made up of plates and angles riveted together and forming flanges and webs.

Built Girder.—A girder made up of structural plates and angles.

Circular Girder.—A girder built in the shape of a circle.

Compound Girder.—Same as a "Built Girder," *q.v.*

Concrete Girder.—A girder built of concrete and usually reinforced with steel.

Continuous Girder.—A girder with more than two supports.

Crane Girder.—A girder either stationary or movable, used for hoisting.

Cross Girder.—Any girder passing across a bridge from one truss or main girder to another, and, generally, perpendicular to the truss or girder planes.

Curb Girder.—A steel or reinforced concrete girder holding up the sidewalk and forming the curb of a roadway.

Curved Girder.—Any girder in the shape of a curve.

Deck Girder.—One of the main girders of a deck bridge, *q.v.*

Deck Plate Girder.—One of the main plate girders in a deck bridge, *q.v.*

Effective Depth of Girder.—See "Depth."

Girder.

Expansion Girder.—Any girder one end of which is allowed to move.

Fascia Girder.—A longitudinal girder at the extreme edge of a structure so finished as to present a neat appearance.

Fish Bellied Girder.—A girder having the top flange horizontal and the bottom flange curved in the shape of a fish's belly.

Flitched Girder.—Same as "Sandwich Girder," *q.v.*

Floor Girder.—Any girder which supports a portion of the floor and its load.

Framed Girder.—A girder constructed of timbers framed together.

Half-latticed Girder or **Half-plate Latticed Girder.**—A lattice girder the ends of which have web plates while the central portion ot the web is latticed.

Half-through Girder.—A loose expression for a girder of a "Half-through Girder-Span," *q.v.*

Half-through Latticed Girder.—A loose expression for a latticed girder of a "Half-through Span," *q.v.*

Half-through Plate Girder.—A loose expression for a plate girder of a "Half-through Span," *q.v.*

I-Beam Girder.—A girder composed of an I-Beam.

Latticed Girder.—A riveted girder having the upper and lower flanges connected by latticing, or by diagonal bars or angles.

Longitudinal Girder.—The main girder in a structure running parallel to the centre line thereof.

Open Web Girder.—Same as "Latticed Girder."

Overhead Girder.—A girder that is overhead—usually moving on an overhead track as in a traveling crane.

Plate Girder.—A girder built of structural plates and angles.

Riveted Girder.—A girder built of plates and angles riveted together throughout.

Sandwich Girder.—A girder or beam having an iron or steel plate inserted between two wooden beams and rigidly bolted thereto.

Skid Girder.—A built-up plate-girder with the web lying in the horizontal plane riveted to the inside of the web members of a truss to protect these members in case of derailment of trains.

Stiffening Girder.—A girder employed to give vertical stiffness, as in the case of a suspension bridge.

Stone Girder.—A lintel.

T-Beam Girder.—A girder built in the shape of the letter T.

Through Girder.—Incorrectly used for a "Half-through Girder." Strictly speaking, a through girder would mean a main girder of a tubular bridge. See "Half-through Span."

Timber Girder.—A girder built mainly of timber.

Transverse Girder.—Same as "Cross Girder," *q.v.*

Traveling Girder.—A girder that moves on rails.

Triangular Girder.—A latticed girder having a system of web members all inclined to the vertical.

Trussed Girder.—A girder stiffened and strengthened by means of trussing, *q.v.*

Truss Girder.—A girder having a latticed web system forming with the flanges a truss in all essential features.

Turntable Girder.—A fish-bellied girder that is used for a turn-table.

Warren Girder.—A latticed triangular girder in which all the triangles are equilateral. Nowadays any triangular girder is spoken of as a Warren Girder.

Girder Bridge.—See "Bridge."

Girder Dogs.—See "Dog."

Girder Guard-rail.—See "Guard-rail."

Girder Hook.—Same as "Girder Dog."

Girder Iron.—See "Iron."

Girder Rail.—See "Rail."

Girder Span.—See "Span."

Girt.—Well braced, as the taut guys on a derrick.

Girth.—The length of the perimeter of a cross-section.

Glacis.—An easy slope of earth.

Gland.—A stuffing box around the piston-rod of an engine. A type of coupling for shafts.

Glass Cutter.—See "Cutter."

Glazed Iron.—See "Iron."

Globe Valve.—See "Valve."

Gneiss.—A rock which consists essentially of the same elements as granite, but having the mica disposed in parallel planes, producing a moderate tendency to cleavage into thick slabs.

Go-devil.—A rough sled for hauling material on snow or ice. A device for exploding dynamite cartridges in holes. A star-shaped tool with a sharp, tapering point.

Gog Press.—Same as "Gag Press." See "Press."

Goose-neck.—An iron or steel hook fitted into the inner end of a boom for temporary attachment to a clamp or an eye bolt. A curved pipe for discharging material from a caisson by means of compressed air. A piece of steel bent in "S" shape. A flexible coupling.

Goose-neck Dolly.—See "Dolly."

Gordon's Formula.—A column formula. Also called Rankine's formula

$$p = \frac{s}{1 + a\frac{l^2}{r^2}}$$

where

p = the allowable unit stress for the column.

s = the allowable unit stress for blocks.

a = a constant depending on end conditions, etc.

l = the unsupported length of the column.

r = the least radius of gyration in reference to an axis normal to the plane in which flexure takes place.

Gouge.—To scoop out. A chisel with a longitudinal curved edge for cutting wood, stone, or metal.

Hand Gouge.—A gouge that is operated by holding it in the hand.

Handle Gouge.—A gouge in the form of a rivet-buster mounted on a handle and used to cut metal.

Governor.—An apparatus consisting of two balls or weights on radial arms pivoted to an upright revolving axis, so arranged as to fly outward by centrifugal reaction and in so doing to raise the radial arms and move a valve. Used as a regulator.

Grab.—A mechanical device for gripping an object, such as a grab-iron.

Grab Bucket.—See "Bucket."

Grade.—The degree of inclination from the horizontal, expressed usually in percentage. To arrange in order according to size or quality. To build a roadway. To lower a hill, especially by hydraulicking.

Break in Grade.—That point where the grade changes. The change itself.

Sub Grade.—The bottom surface of the ballast or pavement.

Grade Crossing.—See "Crossing."

Grade Line.—See "Line."

Grade Plug.—A plug, generally of wood, driven down so that the top is at the exact elevation of the cutting at the place where the said plug is driven.

Grade Point.—A point of established elevation to which a grade is to be brought.

Grade Stake.—See "Stake."

Gradient.—The rate of grade, measured by the rise or fall in one hundred feet, and generally expressed as so much per cent.

Gradienter.—A small screw, with graduated head attached to an engineer's transit for turning off small vertical angles. Used in fixing grades.

Grain.—The smallest unit of weight of the English system. The texture of material. The fork of a river, or a place at which two streams unite. A tine, prong, or spike. The arrangement and direction of the fibres in wood.

Granite.—A rock composed of mica, feldspar, and quartz with a thoroughly crystalline, granular texture.

Banded Granite, or Bastard Granite, or Foliated Granite.—Same as "Gneiss," *q.v.*

Granite-chips.—The chippings left from granite after dressing; the crushings of granite spawls.

Granite Masonry.—See "Masonry."

Granite Screenings.—See "Screenings."

Granitoid.—Small chippings of any granite mixed with cement forming concrete for sidewalks, curbs, etc. Nowadays, any concrete composed of flinty, hard chippings mixed with sand and cement is erroneously termed granitoid.

Granular.—Containing or bearing grains or granules.

Granular Fracture.—See "Fracture."

Granular Structure.—See "Structure."

Graphic Diagram.—See "Diagram."

Graphics.—The method or process of solving problems by means of drawing lines.

Graphic Statics.—See "Statics."

Graphite.—A form of carbon. Used for lead pencils, lubrication of machinery, the rubbing surfaces of wood, and as a conductor in electrical construction. Also employed as a pigment for paints used in structural steel work.

Black Lead Graphite or **Plumbago Graphite.**—Same as "Graphite," *q.v.*

Graphite Paint.—See "Paint."

Grapline or **Grapnel.**—A mechanical device having six arms shaped like an anchor, used to grasp things in deep water.

Grappier's Cement.—See "Cement."

Grapple.—To cast and drag with a grapnel.

Grappling Iron.—An instrument having several iron or steel claws for holding fast to things.

Gravel.—Worn, round fragments of rock, occurring in natural deposits, small enough to pass through a two and one-half inch iron ring and large enough to be retained on a No. 10 screen.

Gravel Concrete.—See "Concrete."

Gravel Sieve.—See "Sieve."

Gravimeter.—An instrument for determining the centre of gravity of a body.

Gravity.—The force of attraction exerted by the earth on bodies near it. Weight as contra-distinguished from mass.

Axis of Gravity.—A line passing through the centres of gravity of successive elemental sections of a body.

Centre of Gravity.—That point in a body about which the weights of all the various portions balance. It is found experimentally by balancing on a knife edge.

Line of Gravity.—The line along which the centre of gravity would move, if the body were free to fall.

Plane of Gravity.—Any vertical plane passing through the centre of gravity of a body.

Specific Gravity.—The ratio of the weight of a unit volume of a substance to the weight of a like volume of the standard substance, such as water.

Gray Column.—See "Column."

Gray Iron.—See "Iron."

Green Concrete.—See "Concrete."
Green Masonry.—See "Masonry."
Green Sand.—See "Sand."
Grillage.—A network of timbers laid across each other, generally at right angles. Frequently placed on the heads of piles for supporting bridge piers and other masonry. Also a network of rolled or built beams put in a pier, to distribute the weight from the shoe, or at the bottom of a shaft to spread quickly the weight over a greatly enlarged area.
Grindle Stone or Grind Stone.—A medium-hard sandstone in the shape of a wheel with a broad face, mounted on a shaft for rotating. Used for sharpening tools by attrition.
Grip.—To seize or hold fast. That portion of a rivet between the two heads after being driven. The thickness of material through which pins, bolts, or rivets penetrate.
Grip of Bolt.—See "Bolt."
Grip of Rivet.—See "Rivet."
Groin or Groyne.—An arch construction formed by two segmental arches intersecting each other at right angles. A construction of timber and stone built out into a stream to retard or deflect the current.
Groined Arch.—See "Arch."
Groove.—A small channel. A cut in material.
Chamfered Groove.—A triangular groove.
Oil Groove.—A groove cut in the interior surface of a bearing to facilitate the spreading of oil over the journal.
Grooved Rail.—Same as "Girder Guard-rail." See "Guard-rail."
Groove Joint.—See "Joint."
Groover.—A cement finisher's hand tool for marking cement surfaces with indentations.
Gross Section.—See "Section."
Ground Finish.—See "Finish."
Ground-hog.—A laborer who digs in the ground or who works under the ground. In contradistinction to a "Sand-hog," who works under water in a pneumatic caisson.
Ground Joint.—See "Joint."
Ground Line.—See "Line."
Grout.—A mortar composed of sand, cement, and water of such liquid consistency that it can easily be poured. To pour grout into a void.
Portland Cement Grout.—Grout in which Portland cement is used.
Grouting.—The pouring of grout.
Grubbing.—The removing of stumps and roots from foundation sites. Applied specially to railway embankments.
Guard.—Any part of an appliance, structure, or attachment designed to prevent the injuring of persons, vehicles, etc. A fender.
Bridge Guard.—A timber or other construction, usually in the form of a large post sunk deep into the ground near the end of a bridge so as to prevent its being struck by either derailed cars or badly shifted loading.
Cattle Guard.—A device consisting usually of sharp-edged, parallel bars placed in a railroad track to prevent stock from getting on the right-of-way.
Dust Guard.—Steel plates placed around rockers, rollers, etc., on shoes to keep out dirt and dust. A thin piece of wood, leather, or fabric fitted to a journal-box to keep out the dust from the bearings, and to prevent the escape of oil and waste from the box.
Hub Guard.—An angle, plate, etc., on corners of concrete, masonry, and similar materials, where vehicular traffic passes, to protect them against injury by the rubbing of wheel hubs.
Ice Guard.—A fender placed at the up-stream end of a bridge pier to divert the ice or else to break up the large cakes into small pieces.

Guard.

Rerailing Guard.—A casting or device attached to the rails near the end of a railway structure so that, if an engine or car is derailed, it will run back on the track.

Rope Guard.—A mechanical device for ropes running over sheaves or through pulley-blocks.

Wheel Guard.—A timber or iron placed on the side of the roadway of a bridge to prevent the wheel hubs from striking the truss or the hand railing.

Guard-rail.—Same as "Felly Plank," *q.v.* Also the inner steel rails between the main rails of a railway track.

Girder Guard-rail.—A street car rail having a ball wider than the ordinary rail and with a slot in it to allow the flanges of the car wheels to roll therein. This rail is often placed on curves.

Inner Guard-rails.—Guard-rails placed between the gauge lines of a car track.

Outer Guard-rails.—Guard-rails placed outside the rails of a car track.

Guard Timber.—A guard-rail made of a timber, usually dapped over the ties for railway bridges.

Gudgeon.—That part of a shaft resting in the bearing, especially when made of a separate piece. A metallic journal-piece let into the end of a wooden shaft. A metallic pin used for securing together two blocks or slabs of stone. A cramp.

Gudgeon Pin.—Same as "Gudgeon," *q.v.*

Guide.—Any apparatus or contrivance intended to direct or to keep to a desired course or motion.

Hammer Guides.—The guides for holding in proper course the motion of a hammer.

Guide Bar.—See "Bar."

Guide Block.—Same as "Guide Bar," *q.v.*

Guide Chair.—A device resembling a chair, used as a guide.

Guide Frame.—A framework used as a guide.

Guide Pile.—See "Pile."

Guide Pin.—See "Pin."

Guide Pulley.—See "Pulley."

Guide Rail.—See "Rail."

Guide Roller.—See "Roller."

Guide Ropes.—See "Ropes."

Guide Screw.—See "Screw."

Guide Tube.—See "Tube."

Guide Wedge.—See "Wedge."

Guide-yoke.—A yoke-shaped piece for supporting the guides in a machine or engine.

Gun.—A device for discharging missles through a tube. Also a hammer operated by air.

Air Gun.—A pneumatic riveting hammer.

Blow Gun.—A barrel or pipe through which material is blown.

Cement Gun.—A barrel or nozzle through which grout is forced by compressed air.

Pneumatic Riveting Gun.—A rivet hammer operated by compressed air.

Riveting Gun.—A riveting hammer.

Gun Metal.—Same as "Bronze," *q.v.*

Gunnel or Gunwale.—The upper edge of a boat's side.

Gunnysack.—A coarse sack of jute or hemp for various uses, such as holding cement in transit or to contain sand for revetment.

Gunpowder.—An explosive mixture of nitre, charcoal, and sulphur.

Gunpowder Pile Driver.—See "Pile Driver."

Gunwale.—Same as "Gunnel," *q.v.*

Gusset.—An angular piece of iron or steel, or a steel plate fastened to angles, channels, or the members of a structure to give strength and stiffness to them, or to connect them to the construction.

Gusset Plate.—See "Plate."

Guy.—A line for bracing the top of a pole, derrick, or any other similar apparatus.

Guy Derrick.—See "Derrick."

Guy Line.—Same as "Guy," *q.v.*

Guy Ring.—See "Ring."

Guy Rope.—See "Rope."

Gypsum.—A chalk formation containing the native hydrous sulphate of calcium.

Gyrate.—To revolve about an axis or a point.

Gyration.—The act of revolving or gyrating.

Centre of Gyration.—A point in a revolving body such that if all the matter of the said body could be collected there, the body would continue to revolve with the same energy as when its parts were in their original places.

Radius of Gyration.—The radius of gyration of a body about a given axis is the distance from the axis of rotation to the centre of gyration, and is equal to the square root of the mean of all the squares of the distances from the axis of rotation to all the points in the body.

Gyroscope.—An instrument consisting of a fly-wheel so mounted that its axis is free to turn in any direction. It is used to illustrate the dynamics of rotating bodies.

H

Hacked Bolt.—See "Bolt."

Hacksaw.—See "Saw."

Haft.—A handle for a cutting tool. To supply with a handle.

Half-and-half Joint.—See "Joint."

Half-hitch Knot.—See "Knot."

Half-latticed Girder.—See "Girder."

Half-plate Latticed Girder.—See "Girder."

Half-round Bastard File.—See "File."

Half-round Rasp.—See "Rasp."

Half-round Wood File.—See "File."

Half-through Plate Girder.—See "Girder."

Half-through Span.—See "Span."

Half-through Truss.—See "Truss."

Halving.—Notching together two timbers which cross each other, so deeply that the joint thickness shall equal only that of one whole timber.

Halving Joint.—See "Joint."

Hammer.—A hand tool consisting of a solid head of metal, wood, or stone set crosswise on a handle. Used for beating, breaking, or driving. The part of a pile driver or of a steam hammer which strikes the blow. To beat or to drive.

Air Hammer.—A machine hammer driven by compressed air, as an air riveting hammer.

Axe Hammer.—A mason's hand tool consisting of a combined hammer and axe on a short handle.

Ballast Hammer.—A double-faced, long-handled, hand-hammer used in tamping ballast under and around ties.

Blocking Hammer.—A hand hammer which has a head that is diamond shaped.

Bricklayer's Hammer.—A hammer having a bent peen, used in brick work.

Bush Hammer.—A mason's finishing hammer having regular rows of points or projections on its faces.

Bust Hammer.—A hammer, used in riveting work, having a rivet buster on one end of the head and a hammer on the other end.

Claw Hammer.—A carpenter's hand hammer having a poll on one end of the head and a claw on the other.

Hammer.

Cleveland Hammer.—One of the numerous makes of air riveting hammers.

Clipping Hammer.—A chisel-edged hammer used for clipping stone, concrete, etc. Nowadays air hammers are so arranged that they can quickly be converted into clipping hammers.

Double-faced Hammer.—A forging apparatus for striking on opposite sides, as in case of a bloom.

Drop Hammer.—A heavy weight, working in guides, which is raised by means of a rope or cable and then allowed to drop.

Duplex Hammer.—Same as "Double Faced Hammer," *q.v.*

Electric Hammer.—An electrical apparatus for working a rock drill.

Engineer's Hammer.—Usually a two faced cylindrical hand hammer, though sometimes having a cylindrical poll and a triangular peen.

Flogging Hammer.—A very large hammer used with a flogging chisel for chipping iron castings.

Foot Hammer.—A machine hammer operated by a treadle.

Forge Hammer.—A hammer used for breaking and trimming rocks.

Friction Hammer.—A drop-hammer raised by the friction of rollers.

Hand Hammer.—Any hammer which is used by hand.

Helve Hammer.—A trip-hammer.

Holding-up Hammer.—A heavy engineer's hammer on a long handle, used in times past for bucking up rivets.

Lift Hammer.—A drop-hammer of a pile driver.

Machinist's Hammer.—A hammer with a round, flat face and a cross peen.

Mason's Hammer.—A square-faced hammer with a peen in line with the handle.

Nasmyth's Steam Hammer.—The earliest form of steam hammer—invented by Nasmyth and Bourdon. Its essentials are a steam cylinder, piston, piston rod carrying a heavy weight for hammer, pile cap and a frame of two I-beams holding the parts together.

Pæane Hammer, or **Pane Hammer.**—Same as "Peen Hammer," *q.v.*

Patent Hammer.—A stone-mason's hammer having knife-like ridges on its face, used for dressing stone.

Pean Hammer.—Same as "Peen Hammer," *q.v.*

Peen Hammer.—A hammer having a peen on one or both faces. See "Peen."

Pein Hammer, or **Pene Hammer.**—Same as "Peen Hammer," *q.v.*

Pile-Driver Hammer, or **Pile Hammer.**—A drop hammer or a steam hammer used in driving piles.

Plow Hammer.—Same as "Engineer's Hammer," *q.v.*

Pneumatic Hammer.—A hammer operated by compressed air.

Power Hammer.—A hammer used for forging work.

Raising Hammer.—A hammer used for deeply dishing metal plates.

Rivet Hammer.—A pneumatic or hand hammer for driving rivets. Also a light engineer's hammer for testing the tightness of rivets after driving.

Scabbing Hammer or **Scaling Hammer.**—A hammer used for loosening and removing scale from steam boilers.

Sledge Hammer.—A medium-sized head of a sledge mounted on a short, thick handle. See "Sledge."

Slogging Hammer.—A very heavy hammer-head on a long handle used in past times for the hand-driving of rivets.

Spalling Hammer.—A heavy axe-like hammer used for roughly dressing stones.

Stamping Hammer.—A small hand hammer having the initials of the firm's name on the pointed end, used by timber inspectors and the like to stamp material which has been inspected and accepted.

Hammer.

Steam Hammer.—A powerful machine hammer consisting of a steam cylinder mounted between guides, a piston, a piston rod with a heavy ram at its lower end, and an anvil at the base of the supporting frame. Steam is admitted to the cylinder by suitable valve mechanism and raises the piston in all cases, while in some it gives an added impulse to the natural fall of the ram. Sixty to eighty blows per minute can be delivered by this apparatus.

Stone Hammer.—A mason's hammer, used for chipping stone.

Striking Hammer.—A quarryman's hammer for striking a rock drill.

Tie Hammer.—A stamping hammer used on ties during inspection.

Tilt Hammer.—A power hammer having a head mounted on the end of a lever that is raised by a cam and then allowed to fall by gravity, although frequently a spring is used to give an additional impulse to the ram.

Trip Hammer.—Same as "Tilt Hammer," *q.v.*

Welding Hammer.—A hammer used in welding metals.

Wrench Hammer.—See "Wrench."

Hammer Axe.—Same as "Axe Hammer," *q.v.*

Hammer Beam.—See "Beam."

Hammer Dressing.—See "Dressing."

Hammered Head.—A head formed on the end of a bar by hammering.

Hammer Guides.—See "Guide."

Hammer-hardened.—Hardened by a process of hammering.

Hammer Head.—See "Head."

Hammer-mark.—A mark left by the blow of a hammer.

Hammer-pick.—A hand tool having a hammer face at one end of the head, and a pointed pick at the other.

Hammer Scale.—See "Scale."

Hammer Tongs.—See "Tongs."

Hammer-wrought.—Anything which has been wrought with a hammer.

Hand Axe.—See "Axe."

Hand-book.—A book containing structural shapes, tables, etc. A "*Vade mecum.*"

Hand-brick.—See "Brick."

Hand-car.—See "Car."

Hand Drill.—See "Drill."

Hand Float.—A wooden or metal trowel. See "Trowel."

Hand Frame.—See "Frame."

Hand Gauge.—See "Gauge."

Hand Gear.—See "Gear."

Hand Glass.—A reading or magnifying glass; used in transit work.

Hand Gouge.—See "Gouge."

Hand Hammer.—See "Hammer."

Hand-hole.—A hole in a piece of metal, wood, etc., large enough for a hand to be inserted. Used in webs and diaphragms at times to facilitate bolting up and riveting in close spaces.

Hand Hook.—See "Hook."

Handle.—To direct or control by hand. That part of anything which is intended to be grasped by the hand.

Handle Gouge.—See "Gouge."

Handle Lock Sleeve.—See "Sleeve."

Hand Level.—See "Level."

Hand Lever.—See "Lever."

Hand Line.—See "Line."

Hand Pile Driver.—See "Pile Driver."

Hand-power Line.—See "Line."

Hand Pump.—See "Pump."
Hand Rail.—See "Rail."
Hand-rail Cap.—See "Cap."
Hand-rail Post.—See "Post."
Hand Reamer.—See "Reamer."
Hand Riveting.—See "Riveting."
Hand-saw.—See "Saw."
Hand-spike.—See "Spike."
Hand Vise.—See "Vise."
Hand Wheel.—See "Wheel."
Hand Winch.—See "Winch."
Hand-wrought.—Worked or shaped by hand.
Hanger Plate.—See "Plate."
Hangers.—Fixtures projecting below a ceiling to support bearings for a line shaft. Also a hip-vertical or suspender of a truss. Also a tension member supporting a floor system in an arch or in a suspension bridge. A beam hanger, *q.v.*
Beam Hanger.—A rod or square bar supporting a floor-beam from a chord pin.
Spandrel Hangers.—Hangers extending from the intrados of the arch to a longitudinal beam forming part of the lower roadway.
Hanging Bridge.—Same as "Suspension Bridge," *q.v.*
Hard-burned.—Overburned, a term used in the manufacture of brick.
Hardening of Steel.—See "Steel."
Hardie.—A steel block having a wedge-shaped edge set in an anvil and used for cutting heated metals.
Hardpan.—A very compact layer or bed of mingled clay and sand or pebbles, or one of shale.
Hard Set.—Same as "Final Set." See "Set."
Hard Steel.—See "Steel."
Hardwood.—See "Wood."
Harmonic Curve.—Same as "Sine Curve." See "Curve."
Harmonic Motion.—A reciprocating, rectilinear motion in which the space described by the moving body or point varies as the sine of time angle. Also the motion described by the projection, on a diameter, of a point moving uniformly in the circumference of a circle.
Hasp.—A clasp that passes over a staple and is fastened to it by a pin or a padlock.
Hatch.—To shade drawings by equidistant parallel lines.
Crosshatching.—The method of shadowing or hatching by using two intersecting sets of parallel lines.
Haul; or Free Haul.—The distance within a given limit, set by the specifications, that material is hauled in construction work.
Average Haul.—The mean distance that material is to be hauled. The distance from the centre of gravity of the cut to the centre of gravity of the fill in respect to all the material moved.
Total Haul.—The total distance that a material is hauled.
Haunch.—That part of an arch between the crown and the skewback.
Hay Steel.—See "Steel."
Head.—A top, upper, or higher part or place. An enlargement resembling the head of an animal.
Bolt Head.—The enlarged end of a bolt having a square or hexagonal shape.
Button Head.—The head of a bar, bolt, or rivet having the shape of a button.
Capstan Head.—That portion of the capstan which contains the holes for receiving the ends of the capstan bars.
Chord Head.—The enlarged head of a chord bar through which the pin passes.
Dog Head.—A round headed tool, used for breaking stones.

Head.

Eye-bar Head.—The enlarged end of the eye-bar through which the pin passes.

Jetty Head.—The projection at the end of a jetty.

Pile Head.—The top of the pile as driven. Also applied to the short pieces sawn off the tops of piles to bring them to a uniform elevation; sometimes called cut-off ends.

Saddle Head.—A hollow casting resting on the heads of columns to sustain another column above and to allow beams to pass through.

Welded Heads.—Heads first worked into the desired shape and then welded on the bars.

Head-block.—A timber at the top of a pile driver which connects the two leads.

Header.—In timber construction, the large beam into which the common joists are framed in forming openings for stairs, chimneys, etc. A cross-beam between and supported by two longitudinal beams, furnishing a rest for one or more intermediate short longitudinal beams. A stone or brick which has its greatest dimension perpendicular to the face of the wall.

Blind Header.—In masonry, a header stone or brick that is hidden from view.

Header and Stretcher Bond.—See "Bond."

Head Frame.—Same as "Gallows Frame," *q.v.*

Heading Chisel.—See "Chisel."

Heading Joint.—See "Joint."

Heading Tool.—See "Tool."

Head Sheaves.—See "Sheaves."

Head Valve.—See "Valve."

Head Wall.—See "Wall."

Headway or **Clear-headway.**—See "Clear-headway."

Heart.—The solid central part of a tree containing neither sap nor albumen.

Per Cent of Heart.—The ratio of the area of heart wood to the entire area of the section of timber.

Ring Heart.—A cleavage along the surface of an annular ring about half way between the heart and the bark of a tree.

Heart Bond.—See "Bond."

Heart Cam.—See "Cam."

Heart Check.—See "Check."

Heart Shake.—See "Shake."

Heart Tie.—See "Tie."

Heart Wood.—See "Wood."

Heat.—A form of energy manifested by the motion of the molecules of a body.

Latent Heat.—The amount of heat absorbed or liberated when a body undergoes a physical change, the temperature of the body remaining constant.

Heater.—An apparatus for heating, a furnace, a forge, a feed water heater, etc.

Heat Test (of Cement).—Same as "Boiling Test." See "Test."

Heel.—The dip of a barge. A form of moulding in masonry. The lower end of a stud or rafter. Applied to almost anything in construction that resembles a heel.

Heel Dolly.—See "Dolly."

Helicoid.—The surface generated by a straight line revolving about the axis of a helix and moving parallel to itself along such axis while following the curve of the helix.

Helix.—A curve of double curvature generated by a point rotating about an axis with a constant radius which moves along the axis in proportion to its angular motion.

Helve.—The handle of an axe.

Helve Hammer.—See "Hammer."

Hemp.—A species of plant which has tough and strong fibres, used for twisting into ropes and cables.

Henequin Hemp.—A kind of hemp which grows in Cuba and parts of Mexico.

Hemp.

Manila Hemp.—A very fine hemp grown in the Philippine Islands.

Sisal Hemp.—Same as "Henequin Hemp," *q.v.*

Virginia Hemp.—An inferior species of hemp grown along the rivers in the Eastern United States.

Water Hemp.—Same as "Virginia Hemp," *q.v.*

Hemp Packing.—See "Packing."

Henequin Hemp.—See "Hemp."

Herring-bone.—The diagonal struts fixed at intervals between the beams of a floor to distribute the load on one beam to adjacent beams and to increase the stiffness of the beams. Also applied to a course of stone laid at an angle so that the stones in each course are placed side by side, and obliquely to the right and to the left in alternate courses.

Herring-bone Dressing.—See "Dressing."

Herring-bone Work.—See "Work."

Hewed Tie.—See "Tie."

Hexagon.—A regular six-sided figure.

Hexagonal Nut.—See "Nut."

Hick Joint.—See "Joint."

Hicky.—A purely field expression employed by bridgemen for almost any contrivance, or part of one, which lacks a specific name. Analogous to "thingumbob."

Hiding Power.—The capacity of a paint or painting material to obscure a surface beneath it.

High Bridge.—See "Bridge."

High Carbon Steel.—See "Steel."

High Steel.—See "Steel."

High Water.—See "Water."

High Water-mark.—See "Water."

Extreme High Water-mark.—See "Water."

Highway.—Formerly restricted to a way or road reserved for the use of ordinary vehicles, pedestrians, or animals, but now it is often used to mean a way or road on which an electric railway also runs.

Highway Bridge.—See "Bridge."

Hinge.—A device for connecting two pieces, so that one may turn about the other.

Joint Hinge or Strap Hinge.—A hinge having long leaves joined at their large ends.

Hinged Arch.—See "Arch."

Hinged End.—The end of a member that is connected to the rest of the structure by a device that permits of a slight rotation. In contradistinction to a fixed end.

Hinged Joint.—See "Joint."

Hinged Lift Bridge.—See "Bridge."

Hinged Pin.—See "Pin."

Hinged Plate.—See "Plate."

Hinged Post.—See "Post."

Hinge-end.—The end of a piece or member that is provided with a hinge.

Hip.—The place at which the top chord meets the batter-brace or inclined end post.

Inner Hip.—The intersection of the inner inclined end post with the top chord in the arm of a swing span.

Outer Hip.—The hip at the outer end of one of the arms of a swing span.

Hip Joint.—See "Joint."

Hip-joint Hood.—A bent tie plate or strap placed over the hip to keep water out of the joint.

Hip Knob.—A finial on the hip of a roof or between the barge boards of a gable.

Hip Roof.—A roof rising directly from the wall-plate on all four sides, and so having no gable.

Hip Vertical.—See "Vertical."

Hitch.—One of the many forms of "Knots," *q.v.*

Running Hitch.—A form of "Running Knot." See "Knot."

Hitcher.—Same as a "Boat Hook." See "Hook."

Hitch Plate.—See "Plate."

Hoarding.—A temporary, close fence of boards placed around work in progress, to exclude stragglers.

Hod.—A form of V-shaped box fixed on the end of a pole, or handle, used on construction work for carrying bricks and mortar.

Hodgkinson's Formula.—An early column formula, devised by Eaton Hodgkinson, based upon Euler's formula; but modified to conform with experiments made at the time.

$$P = (\text{constant})\,\frac{b^4}{l^2}$$

where

P = the load.
b = width of column.
l = length of column.

Hoe.—A tool for digging, scraping, loosening, or mixing material, consisting of a thin blade set transversely to a long handle and at the end thereof.

Shank Mortar-mixer Hoe.—A solid shaft hoe with two circular openings in the blade.

Shank Street Hoe.—A hoe having a solid shank with a solid blade. The common hoe.

Socket Mortar Hoe.—A hoe having a socket-shank and a very heavy solid blade.

Hog Chain.—See "Chain."

Hog Chain Truss.—See "Truss."

Hoist.—A machine for lifting weights or loads of various kinds. To elevate by means of block and tackle or by machinery of any kind.

Air Hoist.—A hoisting device, usually consisting of a cylinder, piston, and piston-rod, operated by compressed air.

Assembling Hoist.—A hoist for lifting and assembling the component parts of trusses, spans, etc., in the shop or yard of a bridge plant.

Builders Hoist.—A hoisting apparatus in which the boiler, engine, gearing, and drum are mounted on the same bed.

Cable Hoist.—A hoist in which cables winding about a drum or drums are used to lift the load.

Chain Hoist.—A hoist in which chains are used for lifting loads.

Electrical Hoist.—A hoist operated by an electric motor.

Hydraulic Hoist.—A hoist operated by hydraulic power.

Lever Hoist.—A form of lifting jack employing a lever.

Outrigger Hoist.—A hoist supported by an outrigger.

Pneumatic Hoist.—Same as "Air Hoist," *q.v.*

Sand Hoist.—An apparatus for lifting sand.

Steam Hoist.—A hoist operated by steam.

Hoist Bridge.—Same as "Lift Bridge." See "Bridge."

Hoisting Block.—See "Block."

Hoisting Cable Rope.—See "Rope."

Hoisting Crab.—See "Crab."

Hoisting Engine.—See "Engine."

Hoisting Jack.—See "Jack."

Hoisting Machine.—Any machine used for hoisting purposes.

Hoisting Shear or Shears.—See "Shear."

Holder-up.—A dolly bar for bucking up rivets. Called, also, "Bucker-up," *q.v.*

Holding-on Bar.—See "Bar."

Holding-up Hammer.—See "Hammer."

Hollow Pile.—See "Pile."

Homogeneous.—Having parts of only one kind. Composed of similar parts or congruous elements.

Homogeneous Steel.—See "Steel."

Honey-comb.—A condition of having cells like those of a honey-comb, occurring at times in concrete, castings, etc.

Hook.—A piece of metal curved or bent so as to catch or grab something. To take hold with a hook.

Bale Hook.—A large hook suspended from the chain of a crane, used in handling unwieldy boxes and materials.

Boat Hook.—A brass or iron hook and a spike fixed to a staff or pole, used for pushing or pulling a boat or barge. At times called a "Gaff-setter," "Setting Pole," "Pole Hook," and a "Hitcher."

Cant Hook.—A wooden bar or lever with an iron hook hinged at the end, used for turning over heavy timbers.

Chain Hook.—A hook which grips a link of a chain, and serves as a cable stopper.

Dog Hook.—A strong hook or a wrench used for separating iron boring rods. Also a bar of iron with a bent prong used in handling logs or timber.

Eye-bar Hook.—See "Dog."

I-Beam Hook.—See "Dog."

Girder Hooks.—See "Dog."

Grab Hook.—A hook formed of four large fish hooks.

Hand Hook.—A tool for twisting iron or steel bars.

Lug Hook.—Same as "Lug Bolt." See "Bolt."

Sister Hook.—A pair of hooks on the same axis facing each other and fitting closely together when in use.

Tackle Hook.—A hook on a pulley-block opposite the becket.

Timber Hook.—See "Dog."

Hook Block.—See "Block."

Hook Bolt.—See "Bolt."

Hook Chain.—See "Chain."

Hooke's Joints.—See "Joint."

Hooke's Law.—This law states that the deformation of an elastic body is proportional to the force applied, or that the intensity of stress is proportional to the rate of strain.

$$\frac{dp}{dl} = E$$

where

dp = the differential intensity of stress.
dl = the differential of the rate of strain
E = a constant.

Hook-eye.—The eye or loop of a hook.

Hoops.—Reinforcing bars, bent into a circular shape like hoops, which surround the longitudinal reinforcement of compression members.

Hopper.—A trough, usually shaped like an inverted frustum of a cone or pyramid, through which materials pass.

Hopper Barge.—A boat having a compartment with a movable bottom to receive the mud or gravel from a dredging machine and to discharge it by gravity.

Horizontal Bracing.—See "Bracing."

Horizontal Clearance.—See "Clearance."

Horizontal Component.—See "Component."
Horizontal Line.—See "Line."
Horizontal Moment.—See "Moment."
Horizontal Pump or **Horizontal Pumping Machine.**—See "Pump."
Horizontal Section.—See "Section."
Horizontal Strut.—See "Strut."
Horizontal Sway Bracing.—See "Bracing."
Horizontal Thrust.—See "Thrust."
Horizontal Truss.—See "Truss."
Horn.—The big end or prong of the shoe on a pile. The round tapering end of an anvil.
Horns.—The stationary arms on a gag-press.
Horse.—A wooden bar with legs for supporting a staging.
Horse Dolly.—See "Dolly."
Horse Gin.—See "Gin."
Horse Pile Driver.—See "Pile Driver."
Horsepower.—A practical unit of power equal to the raising of five hundred and fifty pounds one foot high in one second.
Actual Horsepower or **Brake Horsepower.**—The actual horsepower of an engine as measured at the flywheel by a friction-brake or a dynamometer.
Calculated Horsepower or **Commercial Horsepower.**—Horsepower calculated from the area of the piston.
Dynamic Horsepower.—Same as "Indicated Horsepower," *q.v.*
Effective Horsepower.—Same as "Brake Horsepower," *q.v.*
Electrical Horsepower.—The power in an electric current, usually measured in kilowatts and reduced to horsepower by dividing by 746.
Indicated Horsepower.—The power developed in the cylinder of a steam engine as determined from an indicator diagram. It is equal to the mean effective pressure in pounds per square inch, multiplied by the area of the piston in square inches, by the piston speed in feet per minute, and divided by thirty-three thousand (33,000).
Nominal Horsepower.—Same as "Commercial Horsepower," *q.v.*
Real or True Horsepower.—Same as "Indicated Horsepower," *q.v.*
Horseshoe Riveter.—See "Riveter."
Hose.—A flexible tube or pipe for conveying a liquid or gas to a point where it is required for use.
Air Hose.—A hose for conveying air.
Canvas Hose.—A hose in which the covering is canvas.
Jet Hose.—A strong hose used for jetting purposes.
Rubber Hose.—A hose in which the covering is rubber or a composition of rubber and fabric.
Steam Hose.—A hose conveying steam.
Suction Hose.—A reinforced rubber hose running from a pump to the water supply.
Water Hose.—A hose conveying water.
Hot-box.—A heated journal box of an engine, a vehicle, or any other machinery.
Hot Chisel.—See "Chisel."
Hot Cutter.—See "Cutter."
Hot-pressed Paper.—See "Paper."
Hot Saw.—See "Saw."
Hot Short.—A condition of brittleness in iron or steel due to the presence of sulphur.
Hot-short Iron.—See "Iron."
Housing.—In carpentry, the space left in one piece for the insertion of the extremity of another in order to connect them. The uprights supporting the cross slide of a planer. A covering or roofing. A covering for machinery. That part of the framing which holds the journal box in place.

Housing Iron.—An iron tool used for placing a strand of oakum in a crack.
Housing Joint.—See "Joint."
Housing Maul.—See "Maul."
Howe Truss.—See "Truss."
Hub.—Any rough protuberance or projection. A block of wood for stopping carriage wheels. The central part of a wheel through which the axle passes, and from which the spokes radiate. A surveyor's stake with a tack in the top to denote line and position.
Reference Hub.—A stake driven flush or nearly so with the ground and used to reference, or to tie, a surveyor's line or point.
Triangulation Hub.—A hub used at the corner of a triangulation system.
Hub Guard.—See "Guard."
Hub Plank.—See "Plank."
Hue.—The predominating spectral color in a color mixture.
Humped-up.—Raised in the centre, synonymous with the term "camel-back."
Hurst.—The ring of the helve of a trip-hammer which supports the trunnions. A sand bank near a river, also a shallow in a river.
Hutton's Formula.—An empirical formula for determining wind-pressure on surfaces inclined to the direction of the wind.

$$P_n = P (\sin \alpha)^{(1.84 \cos \alpha - 1)}$$

where P_n = the normal component of wind-pressure,
P = the pressure per square foot on a plane perpendicular to the direction of the wind,
and, α = angle of inclination of the surface with the direction of the wind.

Hydrant.—An apparatus for drawing or discharging water directly from a main or pipe.
Hydrated Lime.—See "Lime."
Hydration.—The process of combining or impregnating with water, or the resulting condition.
Hydraulic Activity.—Same as "Activity of Cement." See "Cement."
Hydraulic Buffer.—See "Buffer."
Hydraulic Cement.—See "Cement."
Hydraulic Condenser.—See "Condenser."
Hydraulic Crane.—See "Crane."
Hydraulic Elevator.—See "Elevator."
Hydraulic Energy.—See "Energy."
Hydraulic Gauge.—Same as "Hydraulic Indicator." See "Indicator."
Hydraulic Hoist.—See "Hoist."
Hydraulic Jack.—See "Jack."
Hydraulic Index.—The ratio of the sum of the weight of silica and alumina to the weight of lime in any cement or cement material.
Hydraulic Indicator.—See "Indicator."
Hydraulic Lime.—See "Lime."
Hydraulic Mortar.—See "Mortar."
Hydraulic Press.—See "Press."
Hydraulic Quickness.—Same as "Hydraulic Activity," *q.v.*
Hydraulic-radius.—The ratio of the area of a cross-section of a stream to the length of the wetted perimeter.
Hydraulic Ram.—See "Ram."
Hydraulic Riveter.—See "Riveter."
Hydraulic Strength.—See "Strength."
Hydraulic Valve.—See "Valve."

Hydraulics.—A branch of the science of the mechanics of fluids which treats of water in motion.

Hydrographic Map.—See "Map."

Hygrometer.—An instrument for measuring the amount of moisture in the atmosphere.

Hygrometric.—Relating to the amount of moisture in the air.

Hyperbola.—A curve such that the difference between the distance from two fixed points, called the foci, to any point on the curve is a constant.

Hyperbolic Logarithm.—See "Logarithm."

I

I-Beam.—See "Beam."

I-Beam Bridge.—See "Bridge."

I-Beam Dogs.—See "Dogs."

I-Beam Girders.—See "Girder."

Ice Apron.—See "Apron."

Ice-break, or **Ice-breaker.**—A structure of masonry or timber (as a pier or a cluster of piles) for the protection of bridge piers against moving ice.

Ice Guard.—See "Guard."

Idle Gear.—See "Gear."

Idle Pulley.—Same as "Loose Pulley." See "Pulley."

Idler, or **Idle Wheel.**—See "Wheel."

Ignition.—Firing; setting on fire; provision for firing.

Impact.—The act of striking. The forcible momentary contact of a moving body with another either moving or at rest.

Coefficient of Impact.—In bridge engineering, the ratio of the effect of a dynamically applied load to that of the same load applied statically, less unity. In other words, it is the factor nearly always less than unity, by which a static load effect must be multiplied in order to find the increment of the dynamic effect of applying the said load in a manner other than statically.

Impact-Allowance Load.—A percentage allowance for impact applied to the equivalent uniform live load. See "Coefficient of Impact."

Impact Load.—See "Load."

Impact-load Stress, or **Impact Stress.**—Same as "Impact Stress." See "Stress."

Impervious.—Not susceptible of being passed through, or penetrated. Generally refers to the percolation of water.

Impost.—The point where an arch rests on a wall or column, or the upper part of a pier from which an arch springs.

Impulse.—The effect of a blow or thrust.

Impulsive Force.—See "Force."

Inch-pound.—A unit of energy or work. The work done in raising a pound vertically through an inch. A unit of moment equal to a force of one pound acting with a lever-arm of one inch.

Inch-Stress.—See "Stress."

Inch-Ton.—See "Ton."

Incise.—To cut into; to engrave. To form by cutting. To carve.

Inclined End Post.—Same as "Batter Post." See "Post."

Inclined Plane.—A plane which makes an angle less than ninety degrees with the horizontal.

Inclined Strut.—See "Strut."

Incrustation.—The act of covering or lining with any foreign substance; also the lining itself.

Indentation Roller.—See "Roller."

Indented.—Notched by a small hollow or depression.

Indented Finish.—See "Finish."

Indeterminate Stress.—See "Stress."

Indicated Horsepower.—See "Horsepower."

Indicator.—A marker. The pointer on a steam gauge or any recording instrument. An instrument for measuring the steam pressure, at various positions of the piston, in an engine cylinder.

Deflection Indicator.—Same as "Deflectometer," *q.v.*

Hydraulic Indicator.—A gauge for indicating the pressure of water.

Indicator Diagram.—See "Diagram."

Indirect Stress.—See "Stress."

Indirect Wind-load.—See "Load."

Indirect Wind-stress.—See "Stress."

Induced Stress.—See "Stress."

Indurated Fibre.—See "Fibre."

Inelastic.—Not elastic; rigid; unyielding.

Inertia.—That property of matter by virtue of which it persists in a state of rest or of uniform motion in a straight line unless some force changes that state. The state or quality of being inert. Indisposition to move or to act. Inertness.

Centre of Inertia.—That point in a body which is so situated that the force or combination of forces requisite for producing motion in the said body, or bringing it to rest or changing its motion in any way, is equivalent to a single force applied at the said point. This point coincides with the center of gravity of the body.

Moment of Inertia.—A function of some property of a body or figure—such as weight, mass, volume, area, length, or position—equal to the summation of the products of the elementary portions of such property, of said body or figure, by the squares of their distances from a given axis.

Polar Moment of Inertia.—The moment of inertia about an axis perpendicular to the plane of rotation or to the plane of the area considered.

Inflection.—A change of curvature from concavity to convexity, or *vice versa.*

Inflection Point.—The point where reversal of curvature occurs. Same as point of contraflexure. See "Contraflexure."

Influence Line.—See "Line."

Ingot.—A large mass of metal cast in a mould.

Bled Ingot.—Ingots from the center of which molten steel has escaped, leaving a cavity.

Ingot Iron.—See "Iron."

Ingot Mould.—See "Mould."

Ingot Steel.—See "Steel."

Ingredient.—A component part or element of a compound or mixture.

Initial Set.—See "Set."

Initial Stress.—See "Stress."

Initial Tension.—See "Tension."

Injecting Condenser.—See "Condenser."

Injector.—An apparatus for forcing water into a steam boiler by means of an enclosed jet or nozzle, through which the steam issues at a high velocity, drawing water through a suction pipe and carrying it along to the boiler in a feed pipe, where, because of its high velocity and force of impact, it is able to overcome the back pressure and enter the boiler.

Inlay.—That which is inserted or laid in something else. To do such insertion. To decorate by insertion.

Inner Guard-rail.—See "Guard-rail."

Inner Hip.—See "Hip."

Inner Lock Tender.—Same as "Inside Lock Tender." See "Tender."

Inside Calipers.—See "Calipers."

Inside Lock-tender.—See "Tender."

Inspection.—Critical examination. Close or careful survey of work, materials, etc.

Inspection Bureau.—An organization or firm composed of a number of inspectors who have determined upon the best and most economic method of inspection and who make a business of doing inspection work on a large scale.

Inspector.—One whose duty is to secure by careful supervision the proper performance of work of any kind, and the proper kind of materials going into the work, all according to the plans and specifications.

Instrument Line.—See "Line."

Instrument-man.—In engineering work, the person who runs a level or a transit.

Insulation.—That state in which the transfer of electricity or heat from a certain body to other bodies is prevented by the interposition of a non-conductor. The non-conductor itself.

Insulator.—A device, fixture, or material which insulates one body from another.

Intake.—The construction work at the head of a pipe or canal for regulating the admission of water to said pipe or canal.

Intensity of Stress.—See "Stress."

Interlaced.—Interwoven; intercrossed.

Interlocking.—The action of linking into each other, or the joining fast together by mutual or reciprocal action.

Interlocking Device.—Any mechanism for interlocking.

Interlocking System.—A system of railroad switches and signals which by a locking mechanism insures the setting of a signal on the movement of a switch, and prevents the movement of more than one switch at a time.

Intermediate Bent.—Any bent between the end bents.

Intermediate Deck.—See "Deck."

Intermediate Girder.—Any girder between the two outside girders.

Intermediate Post.—See "Post."

Intermediate Sill.—See "Sill."

Intermediate Span.—See "Span."

Intermediate Stiffener.—See "Stiffeners."

Intermediate Strut.—See "Strut."

Intermediate Truss.—See "Truss."

Internal Combustion Engines.—See "Engine."

Internal Force.—Same as "Stress," *q.v.*

Internal Stress.—See "Stress."

Intersection.—A place of crossing; cancellation. A point common to two lines or a line and a surface.

Double Intersection.—Same as "Double Cancellation." See "Cancellation."

Multiple Intersection.—Same as "Multiple Cancellation." See "Cancellation."

Single Intersection.—Same as "Single Cancellation" See "Cancellation."

Triple Intersection.—Same as "Triple Cancellation." See "Cancellation."

In the Clear.—Out of the way of moving objects.

Intrados.—The concave curve of an arch. The lower surface of the voussoirs (when in position) of a masonry arch.

Semi-intrados.—That portion of the inner arch curve between the crown of an arch and its springing line.

Invert.—To turn upside down; to turn end for end. The bottom or inverted arch of a sewer or tunnel.

Inverted Arch.—See "Arch."

Inverted Catenary.—See "Catenary."

Inverted Catenary Curve.—See "Curve."

Invoice.—A bill from the seller for goods shipped to the buyer, with information concerning the size, character, weight, etc., of the shipment, given in more or less detail. This bill may or may not have the prices of the goods shown on it.

Invoice.

Shipping Invoice.—An invoice of goods shipped.

Involute.—A curve described by the end of a string as it unwinds from a cylinder while remaining taut.

Involute Tooth.—See "Tooth."

Iron.—A common but important and abundant metal having a specific gravity of about eight. The pure metal has a white, lustrous appearance, does not harden appreciably on quenching, and is strongly attracted by a magnet, although it cannot be made magnetic except when containing carbon, or while an electric current is passed around it. The term is often applied to a tool or utensil made of iron. Also applied to various structural shapes.

Angle Iron.—See "Angle."

Ball Iron.—An iron ore containing clay.

Bar Iron.—Iron made up in the shape of bars.

Blue-short Iron.—Wrought iron that has been injured and rendered brittle by being worked at a blue heat.

Bog Iron.—An iron extracted from ore occurring in marshy ground.

Boom Iron.—See "Boom."

Calking Iron.—See "Calking."

Cast Iron.—Iron as it comes from the smelter containing usually from two and a half to four per cent of carbon.

Channel Iron.—Same as "Rolled Channel." See "Channel."

Charcoal Iron.—Iron made in a furnace where charcoal is used as a fuel.

Chilled Iron.—Iron that is surface-hardened by sudden cooling at the time of casting.

Clamp Iron.—Same as "Clamp," *q.v.*

Cold-short Iron.—Iron that is weak and brittle when cold, due to the presence of phosphorus.

Common Iron.—The poorest quality of commercial iron.

Corrugated Iron.—Sheet iron formed with ridges by passing it between fluted rollers.

Crystalline Iron.—An iron which when broken shows a crystalline fracture.

Derrick Irons.—See "Derrick."

Dog Iron.—See "Dog."

Double Refined Iron.—Iron made by a process of cutting up bars of refined iron, placing the pieces in piles, then reheating and rerolling into shape.

Fibrous Iron.—An iron having a fibrous texture.

Forge Iron.—An inferior grade of iron used for puddling.

Forming Iron.—See "Forming."

Foundry Iron.—An iron used in foundry work.

Galvanized Iron.—Iron coated with zinc.

Girder Iron.—An old term for a structural shape in the form of a girder or I-beam.

Glazed Iron.—An iron containing a large amount of silicon.

Grab Iron.—Same as "Grab," *q.v.*

Grappling Iron.—See "Grappling Iron."

Gray Iron.—A pig iron in which the carbon takes the form of graphite, giving the fracture a dark color.

Hot-short Iron.—Iron that is brittle above a temperature denoted by a medium orange color—due to sulphur.

Housing Iron.—See "Housing Iron."

Ingot Iron.—Soft steel cast in ingots, sometimes with about three per cent of copper added.

Junk Iron.—Same as "Scrap Iron," *q.v.*

Knee Iron.—See "Knee Iron."

Making Iron.—See "Making Iron."

Iron.

Malleable Iron, or **Malleable Cast Iron.**—Cast iron that has been rendered tough and malleable by long-continued high heating, while embedded in hematite, ferric-oxide, etc., and then allowed to cool slowly.

Meteoric Iron.—Iron obtained from meteorites, generally containing about ten per cent of copper.

Mirror Iron.—A white, cast metal containing manganese—largely used in the manufacture of steel. Also called spiegel, spiegel iron, and spiegeleisen.

Mottled Iron.—An iron in which part of the carbon appears as graphite, giving rise to alternate white and gray spots.

Muck Iron.—The lowest grade of wrought iron. Iron ready for the rollers or squeezers.

Norway Iron.—A very pure wrought iron manufactured in Norway, used in making hooks for blocks, etc.

Pig Iron.—A term applied to cast iron when first run from the blast furnace into moulds, giving small-size bars convenient for handling.

Reaming Iron.—See "Reaming-iron."

Red-short Iron.—Iron containing sulphur, copper, or arsenic, which will cause it to crack when bent at a red heat, but permitting of considerable tenacity when cold.

Refined Iron.—An iron made from muck bars cut up, mixed with scrap iron, reheated, and rolled.

Rolled Iron.—An iron that has passed through the rolls.

Sampling Iron.—See "Sampling Iron."

Scrap Iron.—Old iron no longer suitable for its original purpose. Waste iron, junk iron.

Screed-iron or **Scrid-iron.**—See "Screed-iron."

Sheet Iron.—Iron which has been rolled thin into sheets.

Soldering-iron.—See "Soldering-iron."

Swedish Iron.—A very pure wrought iron manufactured in Sweden. Very expensive.

T or **Tee Iron.**—Iron rolled into the shape of a bar having a cross section resembling the letter T.

Toggle Iron.—A connecting detail for a toggle.

Weak Iron.—White, brittle pig-iron.

Weld Iron.—A term suggested for wrought iron, but seldom used.

Wire Iron.—A ductile iron from which wires are manufactured.

Wrought Iron.—In its perfect condition, wrought iron is simply pure iron, but, owing to impurities (to a certain degree) being present, it only approximates to that condition.

Z-Bar Iron.—Iron rolled in the shape of a bar having a cross section resembling the letter Z, but with the web at right angles to the planes of the flanges.

Iron-bound.—Bound together by bands of iron.

Iron-founder.—One who makes iron castings.

Iron Foundry.—See "Foundry."

Iron Furnace.—See "Furnace."

Iron-gray.—A gray hue.

Iron-master.—A manufacturer of iron.

Iron-oxide.—An intimate combination of oxygen and iron, such as rust. Also see "Ochre."

Iron-red.—A red of somewhat orange tint as produced by iron rust.

Iron Rust.—See "Rust."

Iron Sand.—See "Sand."

Iron Saw.—See "Saw."

Iron Scab.—See "Scab."

Iron Scale.—See "Scale."

Iron-smith.—A worker in iron.
Iron-stain.—A stain made by iron rust on some object.
Iron Stone.—See "Stone."
Ironwork.—See "Work."
Iron-worker.—A bridgeman or man who helps erect iron or steel.
Iron-works.—The plant or place where iron structures are fabricated and assembled.
Irregular Course.—See "Course."
Irregular Fracture.—See "Fracture."
Isodomon.—One of the varieties of masonry in Greek architecture in which the blocks forming the courses were of equal thickness and of equal length, and so disposed that the vertical joints of the upper course came over the middle of the blocks in the course immediately below, all blocks being joined by horizontal dowels.
Isometric Projection.—See "Projection."
Isosceles.—Having two legs or sides equal, as in a triangle.
Isotropic.—Having the same physical properties in every direction.

J

Jack.—A lifting apparatus. A mechanical device, appliance, or part of a machine. To pry up or lift with a jack.
  Ball-bearing Jack.—A jack having ball bearings to take up the thrust from the load and reduce the friction of operation.
  Beveled-gear Jack.—A jack operated by power applied through bevel gears.
  Camber Jack.—Any special jack used for putting the initial camber in a truss in place of wooden wedges.
  Differential Jack.—Any jack worked by differential gears.
  Differential Screw-jack.—A screw-jack having a differential screw.
  Hoisting Jack.—A lifting device in which a screw-jack is employed.
  Hydraulic Jack.—A device for lifting heavy weights or exerting great force by means of liquid pressure from a hand-pump connected with a large-bore cylinder and a piston working therein.
  Lazy Jack.—A mechanism consisting of compound levers pivoted together.
  Lever Jack.—A jack worked by a lever.
  Lifting Jack.—A screw jack worked by a worm wheel to which a handle is attached.
  Rack-and-pinion Jack.—A jack using a rack and pinion to attain its lifting motion.
  Rail Jack.—Same as "Track Jack," *q.v.*
  Railroad Jack.—Same as "Track Jack," *q.v.*
  Ratchet Jack.—Any jack worked with a ratchet.
  Screw Jack.—A large screw working in a nut set in a strong frame or forming a part thereof, which in turn serves as a base to carry the load.
  Steamboat Jack.—A ratchet jack similar to and operating on the same principle as a steamboat ratchet, but with bearing shoes at the ends of the screws so that a pressure may be exerted between two objects or parts of a structure.
  Timber Jack.—An apparatus for lifting timber.
  Track Jack.—A lever jack having a tongue near the bottom of the stem and on the side opposite the lever. This tongue can readily be inserted under a rail or tie and a portion of the track raised by pumping the lever.
  Truck Jack.—A lifting jack hung from a truck.
  Whiskey Jack.—A hydraulic jack in which spirits are used instead of water.
  Windlass Jack.—A jack having on the nut which surrounds its screw a crown wheel operated by a pinion and a crank.
Jack Arch.—See "Arch."
Jack-bores.—The bores of a jack either on the inside or the outside.

Jack Chain.—See "Chain."

Jack Engine.—See "Engine."

Jacket.—A covering placed around an object to prevent the escape of heat by radiation.

Steam Jacket.—The jacket placed around a steam pipe or a cylinder of an engine.

Jack-head Pump.—See "Pump."

Jack-knife Bridge.—See "Bridge."

Jack Plane.—See "Plane."

Jack Rafter, or Jack Rib.—See "Rafter."

Jack-roll.—A windlass.

Jack Screw.—Same as "Screw Jack." See "Jack."

Jack Shaft.—See "Shaft."

Jack Stringer.—See "Stringer."

Jack Timber.—A timber in a bay, which, on account of being intercepted by some other piece, is shorter than the rest.

Jag Bolt, or Jag Spike.—Same as "Rag Bolt." See "Bolt."

Jambs.—The sides of an opening through a wall.

Jam Nuts.—Same as "Check Nuts." See "Nuts."

Jaw.—Any part of a construction, which, from its position, shape or use, bears a resemblance to the jaw of an animal.

Jaw Clutch.—See "Clutch."

Jaw Coupling.—Same as "Claw Coupling." See "Coupling."

Jaw Plate.—See "Plate."

Jemmy.—A short crowbar. Also called "Jimmy."

Jet.—A spouting or spurting, as of water or flame, from a small orifice.

Aeration Jet.—A jet of water through which air travels.

Pump Jet.—Same as "Jet Pump." See "Pump."

Rose Jet.—A jet of water issuing through a nozzle having one central opening at the end and five openings around the sides with their axes inclined about forty-five degrees to that of the axis of the nozzle.

Steam Jet.—A flow of steam from an orifice.

Water Jet.—A flow of water, at high velocity, from an orifice or nozzle.

Jet Chain.—See "Chain."

Jet Condenser.—See "Condenser."

Jet Hose.—See "Hose."

Jet Nozzle.—See "Nozzle."

Jet Pipe.—See "Pipe."

Jet Pump.—See "Pump."

Jetted Pile.—See "Pile."

Jetting.—Putting down by means of a jet.

Jetty.—A structure of wood, stone, or mattress extending into a body of water and serving for a wharf or pier, or as a mole, rampart, or wall. Also used to restrain, charge, or direct a current, and to protect a harbor, shore, channel or the like.

Jetty Head.—See "Head."

Jib.—The upper projecting member or arm of a crane supported by a stay.

Jib Crane.—See "Crane."

Jig.—Any tool or fixture used to guide cutting tools.

Jigger.—A small, light, or light-running mechanical contrivance, causing when in use a rapid, jerky motion. Any subordinate mechanical contrivance to which no more definite name is attached. A warehouse crane.

Jigger Pump.—See "Pump."

Jig Saw.—See "Saw."

Jim-crow.—An implement for bending or straightening rails.

Jimmy.—Same as "Jemmy," *q.v.*

Jimmy-wink.—Any short, light, stationary derrick used for raising small loads.

Job.—A particular piece of work. Any undertaking.

Job Work.—See "Work."

Jockey Pulley.—See "Pulley."

Jockey Wheel.—See "Wheel."

Joggle.—A stub tenon on the end of a post or piece of timber, which prevents it from moving laterally.

Joggle Beam.—See "Beam."

Joggle-piece.—The upright member in the middle of a truss; a king post.

Joggle Post.—See "Post."

Joggle Truss.—See "Truss."

Joggle Wheel.—See "Wheel."

Joggle Work.—See "Work."

Joint.—The place or part in which two things or portions of one thing are joined or united. The mechanism, method, or means by which such junction is effected.

Abutting Joint.—A square joint confined to a single plane where the parts meet. In contra-distinction to a lap-joint where the splice is shingled.

Angle Joint.—A joint in which two pieces meet at an angle.

Ball-and-socket Joint, or **Ball Joint.**—A joint having a spherical surface, or a ball working in a socket.

Bead Joint.—Mortar in a masonry joint forming a bead.

Bed Joint.—A horizontal joint or one perpendicular to the line of pressure on the masonry.

Beveled Joint.—An angle joint in which the contact surfaces make equal angles, other than a right angle, with the axes of the parts joined.

Bird's-mouth Joint.—A joint in timber where an inclined member is dapped over a horizontal member.

Breaking Joint.—A joint formed by the ends of several component pieces in one line, no two lines being cut at the same place.

Break Joint.—To overlap pieces so that the joints will not occur near together, avoiding thereby excessive weakening of the member.

Butt Joint.—A joint in which the ends of the pieces are square and press against each other.

Chamfered Joint.—Same as "Mitre Joint," *q.v.*

Compression Joint.—A joint where compression members meet. A splice in a compression member.

Coursing Joint.—A joint between two voussiors in masonry.

Cramp Joint.—A joint between plates of metal in which the edges are thinned by hammering.

Cup-and-ball Joint.—Same as "Ball-and-socket Joint," *q.v.*

Dapped Joint.—A joint made between two pieces by cutting away corresponding portions of each so that they fit together with surfaces flush with each other.

Double-step Joint.—A dapped joint in which the projecting timber has two steps.

Dowel Joint.—A joint that is strengthened by a pin or a dowel.

Elbow Joint.—A joint where two pieces of pipe meet at an angle. A form of pipe-fitting for joining two such pipes.

Expansion Joint.—A joint in which movement for expansion and contraction is allowed.

Faced Joint.—A joint in which the adjacent faces have been planed. Also a voussoir joint that shows on the face of an arch.

Fan-tail Joint.—Same as "Dove-tail Joint," *q.v.*

Fast Joint.—Any joint held fast by means of the addition of one or more bolts.

Female Joint.—The socket of a spigot and faucet joint.

Fish Joint.—A joint between two rails connected by fishplates bolted thereto.

Joint.

Flange Joint.—A joint between two pieces or members terminating in flat disks or flanges which are usually held together by bolts. Used for shafting and pipes.

Flexible Joint.—A joint permitting motion between the parts.

Flush Joint.—A masonry joint filled with mortar and pointed. Also a butt joint not projecting beyond the general level.

Groove Joint.—A joint in a board with a groove in the edge for receiving the tongue.

Ground Joint.—A joint between metallic pieces where the contact surfaces have been ground.

Half-and-half Joint, or **Halving Joint.**—A joint having both parts dapped or gained in equally on their faces.

Heading Joint.—A joint between two planks at right angles to their fibres, or between two voussoirs in the same course.

Hick Joint.—A flush joint in masonry.

Hinged Joint.—A joint in which the parts are connected by a pin, or a similar device, permitting a rotating motion to occur.

Hip-joint.—The junction of the top chord and the batter post.

Hooke's Joint.—A contrivance by which a motion of rotation is communicated from one shaft to another not lying in the same plane.

Housing Joint.—In carpentry, a joint formed between two pieces by removing a portion of one piece to allow the insertion of a part of the other piece.

Jump Joint.—Same as "Butt Joint," *q.v.*

Knuckle Joint.—A flexible joint formed by two abutting links.

Lap Joint.—A joint in which the pieces extend over each other.

Lead Joint.—A joint in a pipe, filled with melted lead.

Lock Joint.—A joint made by the locking together of two halves of a concrete pipe around a pile by inserting wooden keys, soaked with hot tar, in the scarf joints.

Loose Joints.—A joint in which the parts are loosely held together.

Masonry Joint.—A joint between masonry stones that is filled with mortar.

Match Joint.—Same as "Tongue-and-groove Joint," *q.v.*

Miter Joint.—A special case of a beveled joint in which the contact surfaces make angles of forty-five degrees with the axes of their respective parts.

Mortised Joint.—The joint formed between two pieces when one has a hole mortised in it to receive the tenon of the other piece.

Open Joint.—A joint in which the parts are slightly separated.

Overlapping Joint.—Same as "Lap Joint," *q.v.*

Pillow Joint.—Same as "Ball-and-socket Joint, *q.v.*

Pin Joint.—Any joint in which the parts are held together by a pin.

Pipe Joint.—The joint between two pieces of pipe.

Planed Joint.—A joint in which the contact surfaces have been planed or the exterior surfaces finished in a machine.

Putty Joint.—A pipe joint made tight with putty.

Rabbet Joint.—Same as "Half-and-half Joint," *q.v.*

Rail Joint.—The joint between railway rails.

Ring Joint.—A circular flange joint.

Riveted Joint.—A joint in which the parts are held together by rivets or splice plates and rivets.

Rule Joint.—A pivoted joint similar to a hinged joint, *q.v.*

Rust Joint.—A joint between pieces of metal made by a rusting process. Not permissible in good bridge engineering practice.

Saddle Joint.—A sheet metal joint in which one edge overlaps and straddles the upturned edge of the next.

Scarf Joint.—A joint between two pieces made by scarfing or beveling their ends so that when the parts are placed together they form one continuous member.

Joint.

Screw Joint.—A joint in which one piece screws into another or in which both screw into a common sleeve or coupling like the ordinary pipe joint.

Shackle Joint.—A joint formed by a clevis or a shackle with a bolt.

Shove Joint.—A joint in brick-work obtained by shoving the brick on its mortar-bed so as to pile up mortar at its end and thereby fill the vertical joint.

Sleeve Joint.—An expansion joint in conduits, pipe lines, etc., in which the parts fit into a common sleeve.

Slip Joint.—Same as an "Expansion Joint."

Solder Joint.—A joint made by soldering two pieces together.

Splice Joint.—A joint formed by using scabs or splice bars or plates to make the connection between the two parts.

Square Joint.—A timber joint in which the ends are brought squarely together.

Strap Joint.—Same as "Strap Hinge," *q.v.*

Stump Joint.—A joint having a stump to prevent folding except in one direction, as in a folding rule.

Surface Joint.—A connection between metal plates by joining the edges with flanges or laps riveted or soldered to the parts.

Swivel Joint.—A joint utilizing a swivel to permit twisting of the parts with respect to each other.

Sypher Joint.—Same as a "Chamfered Joint," *q.v.*

Tension Joint.—A splice in tension.

Thimble Joint.—An expansion sleeve-joint in a pipe line.

Toggle Joint.—A union of two parts by means of a toggle.

Tongue-and-groove Joint, or **Tongue Joint.**—A joint made by one part having a projecting tongue fitting into a corresponding groove in the other part.

Truss Joint.—Any joint in a truss.

Tuck Joint.—A joint in masonry presenting the appearance of tucks.

Twist Joint.—An ordinary wire splice made by twisting.

Union Joint.—A pipe coupling. Also called a "Pipe Union." See "Union."

Universal Joint.—An arrangement by which one part may be made to move freely in all directions while rotating with another part.

Water Joint.—A joint between parts precluding the passage of water.

Weather Joint.—A masonry joint where the mortar forms an outward sloping surface from the bottom of the upper course to the top of the lower course.

Welded Joint.—The union of metallic pieces by welding.

Wire Joint.—A joint between two wires made by twisting their ends together.

Joint Bolt.—See "Bolt."

Joint Coupling.—See "Coupling."

Joint-end.—The iron end-piece about which another part moves as on a pivot.

Jointer.—A tool for filling the cracks between courses of stone in masonry. A long planer to straighten the edges of boards. A tool for heading a joint.

Joint File.—See "File."

Joint Hinge.—See "Hinge."

Joint of Rupture.—See "Rupture."

Joint Pipe.—See "Pipe."

Joint Splice.—See "Splice."

Joist.—To fit or furnish with joists. One of the horizontal pieces usually laid in equidistant rows to which flooring is nailed.

Binding Joists.—Joists used as girders to sustain common joists.

Bridging Joists.—Common joists.

Steel Joists.—Joists made of steel.

Timber Joists.—Joists made of timber.

Track Joists.—A joist or a stringer which is placed under a track.

Journal.—That part of a shaft or axle which rests on the bearings.

Neck Journal.—A journal having a smaller diameter than that of the main part of the shaft.

Journal Bearing.—See "Bearing."

Journal Box. —See "Box."

Journal Brass.—See "Brass."

Journal Friction.—See "Friction."

Journal Packing.—See "Packing."

Jumbo.—A term descriptive of anything which is unusually large. The cooler for the cinder notch of a blast furnace.

Jump.—An abrupt rise in a level course of masonry.

Jumper.—A dolly; a monkey. A spark from a ladle of molten cast iron.

Jumper Drill.—See "Drill."

Jumping.—Upsetting a bar, etc., or increasing the cross section of same by striking it on end.

Jump Joint.—See "Joint."

Jump-up.—See "Jumping."

Jump Weld.—See "Weld."

Junction Shaft.—See "Shaft."

Junk.—Worn out and discarded material, machinery, structures, etc., that, in general, may be turned to some use; such as old iron or steel which may be remelted and again sold. Same as "Scrap," *q.v.*

Junk-dealer.—One who buys junk.

Junk Iron.—Same as "Scrap Iron." See "Iron."

Jut.—To project out. To shove or butt. A projection.

Jute.—The fibre of a plant grown in India, used for gunny sacks and packing.

Jute Packing.—See "Packing."

Jutty.—A pier, mole, or jetty.

K

Kahn Bars.—See "Bar."

Keckle.—To cover or guard by winding with something.

Kedge.—A small anchor with an iron stock. To move by the aid of an anchor.

Keel.—The principal timber in a boat, vessel, etc., extending from the bow to the stern along the bottom and supporting the whole frame.

Keepers.—The pieces of metal or wood which keep a sliding bolt in its place and guide its motion.

Keg.—A cask-shaped vessel of indefinite size, but in capacity less than a half barrel, usually from five to ten gallons.

Kellogg Truss.—See "Truss."

Kerf.—The space, opening, or narrow slit made in sawing.

Kettle.—A vessel of iron, copper, or other metal, of convenient shape and size, used for heating tar, asphalt, etc.

Key.—Anything that operates a locking mechanism, or that prevents the movement of parts on each other; such as the central stone of an arch or vault. A piece inserted in a longitudinal slot in a shaft to prevent a pulley or gear from slipping; a piece inserted in the back of a board to keep it from warping; a hand tool for controlling a valve, moving a nut, etc.

Adjusting Key.—A wrench in which the jaws are made adjustable.

Cotter Key.—Same as "Cotter," *q.v.*

Key Bed.—See "Bed."

Key Bolt.—Same as "Cotter Pin." See "Pin."

Key Pile.—See "Pile."

Keystone.—See "Stone."

Keystone Column.—See "Column."

Key-way.—A slot cut in a shaft or hub of a gear or pulley to receive the key.

Key Wrench.—See "Wrench."

Kibble.—The bucket used for raising earth, stone, etc., from shafts or mines.

Kill.—To hold molten steel in a laddle, furnace, or crucible until the ebullition of gas ceases and the metal becomes quiet.

Killing.—The act of holding steel to kill it. See "Kill."

Kiln.—A shaft furnace for roasting ore, limestone, etc., where a very high temperature is required.

Cement Kiln.—A rotating furnace having a slight slope, receiving the pulverized, raw material at its upper end and gradually working it toward the lower end where the fire is located.

Lime Kiln.—A furnace in which limestone is calcinated.

Lumber Kiln.—An enclosed chamber artificially warmed, in which sawn lumber is placed to be heated so as to free it from moisture and prevent warping.

Kiln-drying.—An artificial method of seasoning timber, in which it is put into a kiln and exposed to a current of hot air.

Kilowatt.—An electrical unit of power equal to one thousand watts, or 1.3405 horse-power.

Kilowatt-hour.—The customary unit of electric energy, used in the sale of electricity, equal to one thousand watt-hours.

Kinematics.—That branch of the science of mechanics which treats of the motion of bodies without reference to the cause or force producing it.

Kinetic.—Pertaining to or producing motion.

Kinetic Energy.—See "Energy."

Kinetics.—That branch of the science of mechanics which treats of forces causing motion or changing motion in bodies.

King Post.—See "Post."

King-post Truss, or King Truss.—See "Truss."

King Rod.—See "Rod."

Kink.—A knot-like contraction. A twist or a sharp sudden bend in a piece. To twist or contract into knots.

Kip.—A sharp-pointed hill; a jutting point. A stress unit equal to one thousand pounds.

Kish.—The graphite forced out from molten pig iron during its solidification.

Kit.—A kind of cement; lute and putty. A box, chest, or canvas bag for holding tools. To pack in a kit.

Riveting Kit.—A kit of tools for driving field rivets.

Kneaded Rubber.—See "Rubber."

Knee, or Knee Brace.—A short diagonal brace, used to connect a batter brace or a vertical post in a span to an over-head strut.

Knee-braced Trestle.—See "Trestle."

Knee-iron.—An L-shaped angle-iron used to strengthen a joint formed by two timbers in a frame.

Kneeler.—A pad used on the knee by bridgemen, carpenters, etc., for protecting the knee while at work.

Knee-movement.—The movement in a joint like that of a knee.

Knife-edge.—A sharp edge similar to that of a knife blade. However, it is often applied to rather blunt edges.

Knocking-bucker.—A tool made from a strong, flat bar of iron, used for breaking or bucking ore or stone.

Knock Stone.—See "Stone."

Knot.—The hard mass of wood formed in the trunk of a tree at a branch, with the grain distinct and separate from the grain of the trunk. A knob in an arch. An intertwining of the parts of one or more ropes, cords, or strips for the purpose of fastening them together. The act of tying a knot.

Knot.

Becket Bend Knot.—Same as "Sheet Bend Knot," *q.v.*
Blackwall Hitch Knot.—See "Ketchum's Hand Book," pages 444 and 445.
Boat Knot.—See "Ketchum's Hand Book," pages 444 and 445.
Bowline Knot.—See "Ketchum's Hand Book," pages 444 and 445.
Builders' Knot.—Same as a "Clove Hitch," *q.v.*
Carrick Bend Knot.—See "Ketchum's Hand Book," pages 444 and 445.
Cat's Paw Knot.—A knot used on the hook of a pulley-block with a toggle.
Chain Knot.—See "Ketchum's Hand Book," pages 444 and 445.
Clove Hitch.—See "Ketchum's Hand Book," pages 444 and 445.
Double Knot.—See "Ketchum's Hand Book," pages 444 and 445.
Double Flemish Loop Knot.—Same as "Carrick Bend Knot," *q.v.*
Encased Knot.—A timber knot which is surrounded wholly or in part by bark or pitch.
Figure Eight Knot.—See "Ketchum's Hand Book," pages 444 and 445.
Fisherman's Bend Knot.—See "Ketchum's Hand Book," pages 444 and 445.
Flemish Knot.—See "Ketchum's Hand Book, pages 444 and 445.
German Knot.—Same as a "Figure Eight Knot," *q.v.*
Half-hitch Knot.—See "Ketchum's Hand Book," pages 444 and 445.
Large Knot.—A sound knot in timber more than one and a half inches in diameter.
Loose Knot.—A knot in timber, not firmly held in place by growth or position.
Overhang Knot.—Same as "Simple Knot," *q.v.*
Pin Knot.—A sound knot in timber not over one-half inch in diameter.
Pith Knot.—A sound knot in timber with a pith hole not more than one-quarter inch in diameter.
Reef Knot.—Same as a "Square Knot," *q.v.*
Rolling Hitch Knot.—See "Ketchum's Hand Book," pages 444 and 445.
Rotten Knot.—A knot in timber softer than the surrounding wood.
Round Knot.—A knot in timber which is oval or circular in form.
Round Turn and a Half Hitch.—See "Ketchum's Hand Book," pages 444 and 445.
Running Knot.—Any knot made in such a way as to form a noose which tightens as the rope is being pulled.
Sheep Shank Knot.—A form of knot made in a rope to shorten it temporarily.
Sheet Bend.—See "Ketchum's Hand Book," pages 444 and 445.
Sheet Bend Knot with a Toggle.—See "Ketchum's Hand Book," pages 444 and 445.
Simple Knot.—See "Ketchum's Hand Book," pages 444 and 445.
Slip Knot.—See "Ketchum's Hand Book," pages 444 and 445.
Sound Knot.—A knot in timber, which is solid across its face and as hard as the wood surrounding it.
Spike Knot.—A knot in timber which knot is sawn in a lengthwise direction.
Square Knot.—See "Ketchum's Hand Book," pages 444 and 445.
Standard Knot.—A sound knot in timber not over one and a half inches in diameter.
Stevedores' Knot.—See "Ketchum's Hand Book," pages 444 and 445.
Timber Hitch and Half Hitch Knot.—See "Ketchum's Hand Book," pages 444 and 445.
Timber Hitch Knot.—See "Ketchum's Hand Book," pages 444 and 445.
Wall Knot.—See "Ketchum's Hand Book," pages 444 and 445.
Wall Knot Crown.—See "Ketchum's Hand Book," pages 444 and 445.

Knot Maul.—See "Maul."
Knotty.—Having many knots. Said of timber.
Knuckle Gearing.—See "Gearing."
Knuckle Joint.—See "Joint."
K Type Truss.—See "Truss."
Kutter's Formula.—A formula for evaluating the coefficient, C, in the following Chezy formula for the mean velocity of the current in a stream.

$$v = C\sqrt{rs}$$

where v = velocity in feet per second,

C = a coefficient,

$$= \frac{41.6 + \frac{1.811}{n} + \frac{0.00281}{s}}{1 + \left(41.6 + \frac{0.00281}{s}\right)\frac{n}{\sqrt{r}}}$$

r = hydraulic radius,

s = sine of slope,

and n = coefficient of roughness.

Kyanizing.—A process for preventing the decay of wood by impregnating it with chloride of mercury, patented by J. H. Kyan, in 1832.

L

Laced Strut.—See "Strut."

Lacing.—A system of bars not intersecting each other at the middle, used to connect two leaves of a strut in order to make them act as one member.

Angle Lacing.—A system of lacing in which angle-irons are used in place of bars.

Double Lacing.—Erroneously used for "Latticing," *q.v.*

Double Riveted Lacing.—Lacing in which each bar is connected by two rivets at each end.

Single Lacing.—Same as "Lacing," *q.v.*

Lacing Bar.—See "Bar."

Ladder Bracing.—See "Bracing."

Ladder Dredge.—See "Dredge."

Ladder-way.—A space or opening for ascending or descending by a ladder.

Ladder Work.—See "Work."

Ladle.—A large vessel or pot for holding, transporting, and pouring molten metal.

Ladle-barrow.—A special wheel-barrow for carrying a ladle of molten metal.

Lag.—The amount of retardation of some movement, as the lag of the valve in a steam engine. To hang back. The outside covering of a steam boiler to prevent radiation. The vertical timbers nailed to a "Lag Pile," *q.v.* To fasten down with "Lag Screws," *q.v.*

Lag-bellied.—Any construction having a slack, drooping belly.

Lag Bolt.—Erroneously used for "Lag Screw," *q.v.*

Lagged Pile.—See "Pile."

Lagging.—Same as "Sheeting," *q.v.* Also planking or timbers fastened by lag screws.

Lag Screws.—See "Screw."

Laid-up.—A term used in riveting to denote that the dolly bar is tight against the head of the rivet preparatory to driving.

Laitance.—Same as "Laitance of Cement." See "Cement."

Laitier Cement.—See "Cement."

Lamellar Structure.—See "Structure."

Laminar.—Composed of thin plates or layers.

Laminated.—Having plates or scales. Scaly.

Laminated Arch.—See "Arch."

Lampblack.—A fine, black pigment consisting of particles of nearly pure carbon, used for making paints, ink, etc.

Lance Wood.—See "Wood."

Lanch.—Same as "Launch," *q.v.*

Land.—The smooth uncut part of the faceplate of a slide-valve in a steam engine. To put on or to bring to shore.

Landing.—Same as "Land," *q.v.* Also a resting place in a flight of stairs.

Land Slide, or Land Slip.—See "Slide."

Land Tie.—A tie-rod, used to secure a facing wall to the ground. Any anchorage to the ground. A surveying term used to denote the distance from any point to a nearby section corner.

Lang-lay Rope.—Wire rope in which the wires in a strand twist in the same direction as the strands are twisted.

Lantern Pinion.—See "Pinion."

Lantern Wheel.—See "Wheel."

Lanyard.—A cord or line used for convenience or safety in handling articles. A small rope attached to a bucket for taking materials out of a hole.

Lap.—To place one piece upon another, so that its edge extends beyond that of the other.

Lap Joint.—See "Joint."

Lap Riveting.—See "Riveting."

Lap Seam.—See "Seam."

Lap Splice.—See "Splice."

Lap Weld.—See "Weld."

Large Knot.—See "Knot."

Larry.—Same as "Lorry," *q.v.*

Lash.—To secure by tying. To burst or break out.

Lashing.—A cord, rope, wire, or chain for binding or making fast one thing to another.

Latch.—A device for catching or retaining something. A catch. To hold or retain in place with a latch.

Latch-bar.—A bar used for latching.

Latch-catch.—A catch which holds the latch in the locking mechanism of a draw-span.

Latent Heat.—See "Heat."

Lateral.—At right angles to the line of motion; sideways. One of the pieces in a lateral system.

Bottom Laterals or **Lower Laterals.**—Laterals in the plane of the bottom chords.

Top Laterals or **Upper Laterals.**—Laterals in the plane of the upper chords.

Lateral Bracing.—See "Bracing."

Lateral Clearance.—See "Clearance."

Lateral Contraction.—See "Contraction."

Lateral Diagonals.—See "Diagonals."

Lateral Rods.—See "Rod."

Lateral Section.—See "Section."

Lateral Strain.—See "Strain."

Lateral Stress.—See "Stress."

Lateral Struts.—See "Strut."

Lateral System.—A system of tension and compression members, forming the web of a horizontal truss, connecting the opposite chords of a span. Its purposes are to transmit wind pressure to the piers or abutments, to prevent undue vibration from passing trains or other loads, and to hold the chord members to place and line.

Lath.—A thin, narrow strip of wood, used in buildings or for placing between rows of paving blocks in pavements on heavy grades so as to afford better foothold for horses.

Creosoted Lath.—A lath treated with creosote.

Metal Lath.—A perforated metal sheet used for reinforcing concrete.

Timber Lath.—A lath made from timber.

Lathe.—A machine tool for turning various materials, such as metal, wood, bone, etc.

Metal Lathe.—A lathe which is used exclusively for turning metals.

Timber Lathe.—A lathe used exclusively for turning timber.

Latitude.—In surveying, one of the two coordinates of a point—usually referred to the east and west axis in a system of rectangular coordinates.

Lattice.—Same as "Latticing," *q.v.*
Lattice Angle.—See "Angle."
Lattice Bar.—See "Bar."
Lattice Bridge.—See "Bridge."
Lattice Girder.—See "Girder."
Lattice Truss.—See "Truss."
Latticing.—A system of bars crossing each other at mid-length, used to connect the two leaves of a strut in order to make them act as one member. Generally the crossed bars are riveted together at their intersection.
Double Latticing.—Same as "Latticing," *q.v.*
Single Latticing.—Erroneously used for "Lacing," *q.v.*
Launch.—To move heavy bodies by pushing. The sliding of an object, which will float, into the water. A small power boat.
Launching Ways.—See "Ways."
Launching Wedges.—See "Wedges."
Launhardt's Formula.—A formula pertaining to the fatigue of metals.

$$m = p_1 + \frac{n}{m}(f - p_1)$$

where m = maximum stress.
p_1 = repetition limit when $n = 0$.
n = minimum stress.
f = ultimate static strength.
This formula does not properly apply to any part of bridge engineering.
Layer-out.—The person in a bridge shop who lays out the steelwork with templates.
Layout.—A plan or arrangement of the parts of a structure shown on a drawing.
Alternate, or Alternative Layout.—One of two or more different layouts, or schemes, for the same project.
General Layout.—A drawing showing an elevation, plan, and cross section for a structure, and any other notes—such as borings.
Lazy Jack.—See "Jack."
Lazy Pinion.—See "Pinion."
Lead.—The course of a running rope from end to end. In a steam engine, the arrangement of the valves. A passageway. The average distance required to be traveled to remove the earth of an excavation so as to form an embankment, or the average haul.
Lead.—One of the useful metals remarkable for its softness and durability, having a specific gravity of 11.3. To cover, fasten, smooth, or polish with lead.
Blacklead.—A name sometimes used for graphite.
Cast Lead.—Lead which has been cast in a mould.
Milled Lead.—Same as "Sheet Lead," *q.v.*
Red Lead.—An oxide of lead—used as a pigment for paint.
Sheet Lead.—A thin plate of lead made by passing a flat ingot repeatedly through rollers.
White Lead.—A mixture of the carbonate and the hydrated oxides of lead. Used as pigment for paint.
Lead Gray.—Colored like lead.
Leading Beam.—See "Beams."
Leading Line.—Same as "Lead Line." See "Line."
Leading Pile.—See "Pile."
Leading Wheels.—See "Wheels."
Lead Joint.—See "Joint."
Lead Line.—See "Line."
Lead Pipe.—See "Pipe."

Leads.—The two upright timber or steel guides on a pile-driver in which the hammer moves.

Lead-Slag Concrete.—See "Concrete."

Leaf (of a member).—One of the vertical component parts of a built-up member; consisting generally of one or more web plates with top and bottom angles, or one rolled channel. Usually two in number and sometimes three.

Leaf Bridge.—See "Bridge."

Leaf Valve.—Same as "Clack Valve." See "Valve."

Leaf Work.—See "Work."

Leak.—The escape of gas, air, water, or steam through an opening. A gutter is often termed a leak. To drip or ooze out of an aperture of any sort.

Least-work.—A method of determining stresses in the members of a redundant system.

Principle of Least-work.—The stresses in the members of a redundant system have such values that the internal energy of all the stresses is a minimum.

Leaves.—The cogs of pinions. The portions of a moving bridge which actually revolve. The two or more main components of a built member of a truss or trestle.

Ledge.—A part projecting over like a shelf. A narrow strip of board nailed across other boards to hold them together.

Ledger.—A bar, beam, or stone that lies flat, or horizontal. A piece of timber used in forming a scaffold. A book for keeping accounts.

Leeward.—The side opposite to that from which the wind comes.

Left-handed Nut.—See "Nut."

Left-handed Thread.—See "Thread."

Left-handed Screw.—See "Screw."

Leg.—Anything that resembles the limb of an animal or serves a similar purpose, as in supporting a load; e.g., the inclined legs in an A frame, or the two portions of an angle-iron separated by the bend.

Stiff Leg.—A leg capable of taking compression.

Leg Bridge.—See "Bridge."

Lemniscate.—A curve resembling a figure eight. More precisely defined as the locus of the point at which the tangent to the equilateral hyperbola meets the perpendicular let fall upon it from the center.

Length.—Extension from end to end. Distance measured along a line.

Effective Length.—That length of a member or structure used for the purpose of designing it. In a girder or truss the distance between the points of support.

Gauge Length.—The original length marked on a test bar for the determination of the elongation.

Panel Length.—The distance between two adjacent panel points in the same chord of a truss.

Unsupported Length.—The length of a compression member between the nearest points of lateral restraint.

Lens.—A piece of transparent substance, usually glass, bounded by two curved surfaces having the power of refracting light.

Lenticular Arch.—See "Arch."

Lenticular Truss.—See "Truss."

Letting.—The awarding of a contract to a bidder.

Sub-letting.—The re-awarding of a contract or a portion thereof by the successful bidder to another party.

Level.—To make horizontal, or to bring into a plane parallel to the horizon. To bring to a common level. To work with a leveling instrument. An instrument for securing a horizontal line of sight.

Carpenter's Level.—A plummet attached to a wooden T having a line through the attachment of the plumb-line perpendicular to the edge of the wood. Also a "Spirit Level," *q.v.*

Level.

Dumpy Level.—An engineer's level having a short telescope rigidly fixed to the supporting bar and vertical axis.

Engineer's Level.—A leveling instrument consisting of a telescope, having cross hairs, mounted on a supporting frame which can be brought to a level by means of screws, and which can be rotated about a vertical axis. A tripod serves to hold the instrument at a convenient height for the observer.

Flying Level.—A hasty, preliminary leveling over a proposed route.

Hand Level.—A small leveling instrument held in the hand for approximating differences in elevation.

Locke Level.—A type of hand-level consisting of a small tube with a spirit bubble mounted on the upper side and a refracting prism or a reflector to show the bubble in the field of vision.

Precise Level.—A modification of the Y level with improvements and additions permitting of more accurate work.

Spirit Level.—A long block of wood or a metal frame of similar size and shape holding a short, slightly curved glass tube closed at the ends and nearly filled with ether. The bubble, thus produced, will come to the center of the tube when the apparatus is level.

Surveyor's Level.—Similar to "Engineer's Level," *q.v.*

Water Level.—The elevation at which water stands.

Y Level.—A leveling instrument having its telescope in Y standards, permitting of a rotation therein and a removal therefrom with a reversal of ends, so as to facilitate the process of adjusting.

Level Book.—A field book in which to record level notes.

Leveler.—One who does leveling work. A small stone used illegitimately in masonry to adjust the elevation of a large, cut stone.

Leveling Instrument.—A surveyor's or engineer's level, *q.v.*

Leveling Pole, or Leveling Rod, or Leveling Staff.—See "Rod."

Level-man.—The man in a survey party who operates the level.

Level-notes.—Records of back-sights, heights of instrument, foresights, and elevations as written by the observer in the level book.

Lever. A mechanical element, or simple machine, consisting of a bar or rigid piece of any shape which is acted upon by two forces severally tending to rotate it about a fixed axis. Any rod or bar used for prying.

Hand Lever.—A hand tool consisting of a small steel bar for prying. The handle by which an engine or a machine is started.

Laws of the Lever.—An early day expression used to denote the conditions of equilibrium of three forces in one plane. They are as follows:

First.—The three parallel forces applied to one body must balance each other and lie in the same plane.

Second.—The two extreme forces must act in the same direction.

Third.—The middle force must act in the opposite direction.

Fourth.—The magnitude of each force must be proportional to the distance between the other two.

Link Lever.—A controlling lever for moving the link of a valve gear in a steam engine.

Leverage.—Lever power, or the arrangement by which lever power is gained.

Lever-arm.—The perpendicular distance from the centre of moments to the line of action of a force; or in the case of a couple, the distance between the lines of action of the two equal and parallel forces.

Lever Draw Bridge.—See "Bridge."

Lever Hoist.—See "Hoist."

Lever Jack.—See "Jack."

Lever Valve.—See "Valve."

Lewis.—A device composed of two or three pieces of metal, let into a wedge-shaped hole in a block of stone, and having a ring or loop at their upper end for attaching the hook of a hoisting apparatus.

Lewis Bolt.—See "Bolt."

Lewis-hole.—The hole drilled in a block of stone for the reception of a lewis.

Lift.—To move or heave upward. The apparatus used in lifting. An elevator, a hoist.

Sand Lift.—Same as "Sand Hoist," *q.v.*

Lift Bridge.—See "Bridge."

Lift Hammer.—See "Hammer."

Lifting Bridge.—Same as "Lift Bridge," *q.v.*

Lifting Deck.—See "Deck."

Lifting Jack.—See "Jack."

Lift Pump.—See "Pump."

Lift Span.—See "Span."

Lighter.—A scow, barge, raft, or other small vessel for unloading ships at a distance from the shore.

Lime.—A product made by heating limestone, marble, or shells to a high temperature in kilns. As it comes from the kilns in a pure state, it is (CaO) calcium oxide.

Air Slaked Lime.—Lime which has absorbed moisture from the air.

Caustic Lime.—Same as "Quick Lime," *q.v.*

Common Lime.—Same as "Lime," *q.v.*

Fat Lime.—A lime rich in protoxide of calcium.

Flour of Lime.—Air-slaked lime reduced to the consistency of flour.

Free Lime.—In cement, lime that has not combined with the silica and alumina.

Hydrated Lime.—Same as "Slaked Lime," *q.v.*

Hydraulic Lime.—A lime made from limestone containing clay or silica which, during calcination, enters into combination with a portion of the lime and thereby gives it the additional property of hardening under water.

Magnesian Lime.—A term applied to limes containing more than five per cent of magnesia.

Meager Lime.—A lime that is lacking in the protoxide of calcium.

Neat Lime.—Lime mixed with water and used for plastering or whitewashing.

Paste Lime or **Putty Lime.**—A thick mixture of lime and water.

Quick Lime.—The commercial lime, or a calcium oxide, which has not been hydrated.

Rich Lime.—Same as "Fat Lime," *q.v.*

Silicate of Lime.—A union of silica and lime (SiO_2CaO).

Slaked Lime.—A lime that has been mixed with water, or hydrated.

White Lime.—A solution or preparation of lime used for white-washing.

Lime-cement Mortar.—See "Mortar."

Lime Kiln.—See "Kiln."

Lime Mortar.—See "Mortar."

Limestone.—A rock of sedimentary origin consisting largely of calcium carbonate ($CaCO_3$).

Dolomitic Limestone.—A limestone containing more than one-third part of carbonate of magnesia.

Magnesian Limestone.—A limestone containing one-third part or less of carbonate of magnesia.

Oölitic Limestone.—A granular limestone in which each grain approximates to the form of a sphere, producing a resemblance in the rock to the roe of a fish; hence the name.

Lime-wash.—Same as white-wash or white lime, *q.v.* To white-wash.

Limit Load.—See "Load."

Limit of Elasticity.—Same as "Elastic Limit," *q.v.*

Limits.—The precise boundaries between two contiguous regions of magnitude or quantity.

Limnoria.—A small crustacean about the size of a grain of rice requiring both air and water for its existence. It works on the surface of wood with its claws or mandibles taking off at one time a layer about one-half inch thick. It is usually most active in brackish waters at low water level.

Linch Pin.—See "Pin."

Line.—A unit of length, as one tenth or one twelfth of an inch. A row of anything. A limit, division, or boundary. A length without breadth, or the trace of a moving point. A string, cord, or slender rope. A mark drawn by a pen or pencil. To cover or fill the inside of anything. To keep things in line. A railway.

Abutment Line.—The closing line of an equilibrium polygon.

Air Line.—The shortest distance between two points on the earth's surface.

Base Line.—A line adopted as a fundamental line in a survey from which other lines are run. Used in triangulation work.

Broken Line.—Any line composed of two or more straight lines.

Carpenter's Line.—Any light cord or string stretched between nails, used by carpenters to line up work.

Centre Line.—A line connecting the centre points of anything.

Chalk Line.—A cord rubbed with chalk, used for marking lines on surfaces by being held taut and snapped with the fingers. Also the mark left by such a process.

Clearance Line.—A line on a diagram showing the minimum clearance allowed.

Closing Line.—The last line or side of a polygon, drawn or surveyed, which encloses the area.

Contour Line.—A line joining points having or representing equal elevations.

Curved Line.—A line which changes direction at every point.

Datum Line.—A line of reference. This term is sometimes incorrectly used for "Datum Plane."

Fall Line.—A rope or steel cable used with pulley-blocks in hoisting.

Grade Line.—A line connecting grade points.

Ground Line.—The line of intersection of the vertical and horizontal planes of reference. The line showing the surface of the ground on a profile.

Guy Line.—Same as "Guy," *q.v.*

Hand Line.—A small rope used in guiding moving, suspended objects.

Horizontal Line.—Any line in a horizontal plane.

Influence Line.—A line which represents the variation of moment, shear, stress, deflection, or similar function at a particular point in the structure, due to a load of unity moving across it.

Leading Line, or Lead Line.—A line attached to the hammer in a pile driver. The line or cable which runs from the load to be lifted to the first sheave or block in a hoisting tackle.

Lead Line.—The line attached to the sounding lead for measuring the depths of water, marked in either fathoms or feet.

Load Line.—A rope or cable which carries the load. In graphic statics, the line of a force polygon on which the loads are laid off.

Meander Line.—A traverse line run along the banks of a stream so as to conform with its changes of direction and to enable it to be plotted.

Mooring Line.—A line used to fasten an object. Generally applied to a vessel or barge.

Mud Line.—The line of intersection of the mud surface with an object imbedded therein. The earth line in a profile of a river crossing.

Neat Line.—The true face line of a building regardless of the projections of the stones. A line back of or inside of incidental projections.

Periphery Lines.—Lines forming the periphery of an object or figure.

Line.

Pile Line.—The rope or cable used to pick up a pile and land it in place between the leads of a pile driver.

Pipe Line.—A series of pipes connected up to form one system.

Pitch Line.—Same as "Pitch Circle," *q.v.*

Plumb Line.—A vertical line. A tool consisting of a weight suspended by a cord, used for plumbing members of a structure, or for setting a surveying instrument over a point.

Rupture Line.—The line along which rupture occurs or would occur if the piece were tested to destruction.

Snubbing Line.—A line or rope carried on the forward end of a barge or raft, used to pass around a post so as to check the momentum of the floating mass.

Springing Line.—The line connecting the lower edges of the springers in a masonry arch; or, in general, the line connecting the two opposite points where the curve of the intrados intersects or becomes tangent to the face of the supports of the arch.

Straight Line.—The shortest distance between two points, a line which has no curves nor angles.

Tag Line, or Tail Line.—A rope attached to a load in order to direct its movement. A loose hanging line for pulling down an object. A tripping line for a collapsible bucket.

Tie Line.—A hitching rope for a barge or other vessel.

Traverse Line.—Often called a "Traverse." A series of connected lines of which the lengths and bearings have been determined.

Trip Line.—A rope by which a trip is operated.

Tow Line.—Any line used for towing.

Vertical Line.—Any line which is perpendicular to a horizontal plane.

Water Line.—The intersection of the free surface of a body of water with any plane or object.

Lineal.—Relating to length only. Often written "Linear."

Lineal-foot.—A running foot.

Linear.—Same as "Lineal," *q.v.*

Linear Arch.—See "Arch."

Linear Velocity.—See "Velocity."

Line of Gravity.—See "Gravity."

Line of Resistance.—See "Resistance."

Lining.—The covering of the inner surface of anything.

Link.—A ring or element of a chain, a loop. Anything serving to connect one thing to another. To unite or connect. A crook or winding in a river.

Repair Link.—A split link used temporarily for repairing a chain.

Snap Link.—An open link with a movable part operated by a spring, used to connect chains.

Link Belting.—See "Belting."

Link Block.—See "Block."

Link Chain.—See "Chain."

Link Lever.—See "Lever."

Link-motion.—In steam engines, a system of gearing for controlling the valves, regulating the position of the cut-off, and starting or reversing the engine.

Lintel.—A horizontal beam across an opening in a wall. Same as "Breast Summer," *q.v.*

Linville Truss.—See "Truss."

Lip Washer.—See "Washer."

Liquidate.—To pay off a debt.

Liquidated Damages.—Damages determined, as to amount, either by agreement or by a judgment.

Live Load.—See "Load."

Live Load Stress.—See "Stress."

Load.—The weight carried by a beam, girder, truss, span, or structure of any sort, or any part of such structure, including its own weight.

Apex Load.—The load at a panel point of a truss.

Axle Load.—The load which comes on an axle of a wagon, car, or locomotive and is in turn transferred to the structure.

Breaking Load.—A load which when placed upon a structure or test piece would just be great enough to break it.

Centrifugal Load.—The horizontal load on a structure produced by the centrifugal reaction caused by the velocity and mass of a moving train as it passes around a curve.

Concentrated Load.—A load that is concentrated at a point or distributed over a very small area.

Crippling Load.—A load which, if put on a member or a structure, will disable or weaken it.

Dead Load.—The weight of all the parts of a bridge itself and anything that may remain upon it for any length of time, such as tracks, water mains, telephone and telegraph lines, snow, dirt, moisture, etc.

Eccentric Load.—A load which is applied to one side of the axis of resistance, and which, consequently, produces a bending moment on the piece considered.

Equivalent Uniform Live Load.—A load of the same weight for each unit of its length and practically equivalent in its effect to an assumed typical live load composed of varying wheel concentrations with various wheel spacings.

Excess Load.—An "Over Load," *q.v.* See also "Locomotive Excess."

Fixed Load.—Any determined load.

Impact-allowance Load.—A percentage allowance for impact from the live load.

Impact Load.—A load due to "Impact," *q.v.*

Indirect Wind Load.—A transferred wind load.

Limit Load.—The greatest load which a structure is permitted to carry as set forth in the specifications. A safety load.

Live Load.—A moving load on a structure.

Moving Load.—An advancing load on a structure.

Over Load.—A load which produces intensities of stress beyond the allowable unit stresses.

Panel Load.—Same as "Apex Load," *q.v.*

Permanent Load.—Same as "Dead Load," *q.v.*

Proof Load.—The greatest load that can be applied to a member without producing permanent distortion.

Quiescent Load.—A load that is not in motion.

Rolling Load.—Same as "Moving Load," *q.v.*

Safe Load.—Any load which does not produce stresses, in the members, having higher intensities than those allowed in the specifications.

Static Load.—Same as "Dead Load," *q.v.*

Test Load.—A live load applied to any finished construction as an ocular proof of its safety. It is of no real value.

Traction Load.—A load due to the kick back of the locomotive drivers running on the rails (equal to the draw-bar pull), or the thrust from a braked train.

Transferred Load.—A load which has been carried over from another part of the structure to the member in question.

Transverse Load.—A load which is applied perpendicularly to the plane of the longitudinal axis of the member or the structure, such as a wind load.

Unbalanced Load.—A load without a counterpoise. Refers generally to loads from locomotive drivers.

Load.

Uniform Load.—A load which is uniformly distributed, or the same per lineal foot of span.

Wheel Loads.—Loads on the different wheels of a locomotive. Also a system of wheel loadings.

Wind Loads.—A load on a structure due to the pressure of the wind.

Working Load.—A safe load established by the specifications.

Load Diagram.—See "Diagram."

Loading.—A system of loads on a structure. The act of placing loads on vehicles.

Load Line.—See "Line."

Loblolly Pine.—See "Pine."

Lock.—To close and fasten in. Any form of a brake or drag for wheels which prevents their turning. A barrier to confine water in a stream. A portion of the air shaft to a caisson shut off by two doors and used by the workmen for entering or leaving the caisson.

Nut Lock.—A device for preventing a nut from turning.

Lock Bar.—See "Bar."

Locke Level.—See "Level."

Locking Gear.—See "Gear."

Lock Joint.—See "Joint."

Lock Nut.—See "Nut."

Lock Nut Washer.—See "Washer."

Lock Pit.—See "Pit."

Lock Sleeve.—See "Sleeve."

Locomotive.—A steam engine which travels on wheels turned by its own power, or an engine designed and adapted to travel on a railroad. A railroad engine.

American Locomotive.—A passenger locomotive having four pilot, four driving, and no trailer wheels.

Atlantic Locomotive.—A passenger locomotive having four pilot, four driving, and two trailer wheels.

Back Truck Locomotive.—A locomotive having a truck, with a pair of wheels, under its rear end as well as a truck in front of the driving wheels.

Belgian Tank Locomotive.—A locomotive having a tank on each side of the boiler.

Compound Locomotive.—A freight locomotive having two or more cylinders (sometimes four) on each side, in which the steam is worked expansively from cylinder to cylinder.

Consolidation Locomotive.—A freight locomotive having two pilot, eight driving, and no trailer wheels.

Dinkey or Dinky Locomotive.—Any small locomotive for hauling earth, rock, etc., which runs on a narrow-gauge track. Used largely by contractors.

Double Ender Locomotive.—A locomotive having two fire boxes and two sets of engines.

Double Piston Locomotive.—A locomotive in which each cylinder has two pistons with rods projecting from each end, and working on crank-pins set at 180 degrees from each other.

Double Truck Tank Locomotive.—A locomotive which has two trucks, and carries boilers and tenders on a single frame.

Electric Locomotive.—A locomotive run by an electric current.

Fireless Locomotive.—A locomotive driven by compressed air or by steam generated from highly heated water carried in strongly constructed tanks.

Four-cylinder Locomotive.—A locomotive having four cylinders and two systems of driving wheels.

Freight Locomotive.—Any heavy locomotive which draws freight cars. Usually one with heavy wheel concentrations and small drivers.

Locomotive.

Geared Locomotive.—A locomotive in which the motion of the engine is conveyed by gearing to the drivers.

Mallet Locomotive.—A heavy freight locomotive having two sets of six, eight, or ten driving wheels each.

Mikado Locomotive.—A heavy locomotive having two pilot, eight driving, and two trailer wheels.

Mogul Locomotive.—A type of freight engine with three coupled driving wheels on each side and a swinging, two-wheeled truck in front.

Mountain Locomotive.—A heavy locomotive having four pilot, eight driving, and two trailer wheels.

Pacific Type Locomotive.—A locomotive having four pilot wheels, six driving wheels, and two trailers.

Passenger Locomotive.—A locomotive having large drivers used for hauling passenger cars.

Prairie Type Locomotive.—A locomotive having two pilot, six driving, and two trailer wheels.

Shay Locomotive.—A geared locomotive.

Switching Locomotive.—A locomotive used mainly for switching cars in the yards.

Tank Locomotive.—A locomotive permanently connected with its tender.

Ten-Wheeled Locomotive.—A locomotive with six coupled driving wheels, and a four-wheeled truck in front of the drivers.

Locomotive Balance.—A spring used in place of a weight to control the safety valve of a locomotive.

Locomotive Boiler.—See "Boiler."

Locomotive Car.—See "Car."

Locomotive Crane.—See "Crane."

Locomotive Diagram.—See "Diagram."

Locomotive Driver.—See "Driver."

Locomotive Excess-load.—An early method for computing stresses in a span by the use of a uniform carload with one or more engine excesses. No longer employed in American bridge designing.

Double Locomotive Excess-Load.—A live load composed of a uniform carload per lineal foot preceded by one concentrated load and followed by another about fifty feet behind, or the length of a locomotive with its tender. This loading is no longer used in American bridge engineering.

Single Locomotive Excess-load.—A live load in which a single concentration is followed by a uniform car load.

Locomotive-pilot.—The truck and its wheels set in front of the drivers of a locomotive.

Locomotive Pump.—See "Pump."

Locus.—In mathematics, a curve considered as generated by a moving point, or a surface considered as generated by a moving line; the partly indeterminate position of a point subject to an equation or to two equations in analytic geometry; a curve considered as generated by its moving tangent or by a moving curve of which it is the envelope; any system of points, lines, or planes defined by general conditions, and, in general, partly indeterminate.

Log.—An abbreviation for "Logarithm," *q.v.* A bulky piece or stick of timber.

Logarithm.—The exponent of the power to which a fixed number, called the base, must be raised in order to produce a given number.

Briggs' Logarithm or Common Logarithm.—A system of logarithms in which the base is ten.

Hyperbolic Logarithm, or Naperian Logarithm, or Natural Logarithm.—A system of logarithms in which the base is 2.71828+.

Logarithmic Curve.—See "Curve."

Logarithmic Spiral Curve.—See "Curve."

Logarithmic Table.—A table which gives the logarithms of consecutive numbers and of trigonometric functions of angles.

Lomas Nut.—See "Nut."

Long Column.—See "Column."

Longitude.—Same as "Departure," *q. v.*

Longitudinal Axis.—See "Axis."

Longitudinal Beam.—See "Beam."

Longitudinal Bracing.—See "Bracing."

Longitudinal Component.—See "Component."

Longitudinal Girder.—See "Girder."

Longitudinal Pinion.—See "Pinion."

Longitudinal Section.—See "Section."

Longitudinal Shear.—See "Shear."

Longitudinal Stress.—See "Stress."

Longitudinal Thrust.—See "Thrust."

Longitudinal Tie Girder.—See "Girder."

Long Leaf Yellow Pine.—See "Pine."

Long Ton.—See "Ton."

Loop.—A folding or doubling of a string, cord, or chain. The bend in a river. To fasten or secure with loops. A knot or burr, often of large size, on trees. A slotted bar or ring at each side of any piece of machinery, designed to control the movement of another part. An elongated eye in a small eye-bar.

Bent Loop.—A loop eye-bar in which the loop is bent in respect to the direction of the length of the bar.

Loop Eye.—See "Eye."

Loop Tackle.—See "Tackle."

Loose Joint.—See "Joint."

Loose Knot.—See "Knot."

Loricated Pipe.—See "Pipe."

Lorry.—An English term for a tramway wagon, *i.e.*, a long wagon having a very low platform and four small wheels used for carrying freight. At the present time it is used to denote a motor truck and also a hand car. In the United States, a drop-bottomed car running on a track, such as that around a blast furnace. Also spelled "Larry."

Lorry Rail or **Lorry Track.**—See "Track."

Low Bridge.—See "Bridge."

Lower Chord.—Same as "Bottom Chord." See "Chord."

Lower Deck.—See "Deck."

Lower Falsework.—See "Falsework."

Lower Lateral Bracing.—See "Bracing."

Lower Laterals.—See "Laterals."

Low Steel.—See "Steel."

Low Water.—See "Water."

Low Water Mark.—See "Water."

Lubricant.—Any material used on rubbing surfaces to reduce the friction and thereby also the resistance to motion.

Lubricate.—To reduce the friction of two surfaces that are in contact by the interposition of oil or other material so as to lessen the friction between them when one moves on the other.

Lubrication.—The act of lubricating; the state of being lubricated.

Luff.—To bring a vessel into the wind. To swing the boom of a derrick.

Luff Tackle.—See "Tackle."

Lug.—Any kind of a projection for carrying or supporting something.

Angle Lug.—Same as "Clip Angle." See "Angle."

Lug Angle.—Same as "Clip Angle." See "Angle."

Lug Bolt.—See "Bolt."

Lug Hook.—Same as "Lug Bolt." See "Bolt."

Lumber.—Timber that has been sawed or split for use.

Lumber Kiln.—See "Kiln."

Lump-sum.—An adjective applied to the method of paying for different kinds of work, all lumped together as one unit. A single payment.

Luster.—A term used in describing the character of the reflections obtained from the fractured surfaces of minerals and from the broken ends of metal test-pieces.

Lute.—A mixture of fire-clay, used to seal cracks when heat is applied.

M

Macadam.—A type of pavement consisting of broken stone laid in courses and rolled.

MacArthur Pile.—Same as "Pedestal pile." See "Pile."

Machine.—An apparatus, instrument, or mechanical element for the transmission of force and the conversion of motion.

Machine Bolt.—See "Bolt."

Machine Chain.—See "Chain."

Machine Drill.—See "Drill."

Machine Finish.—See "Finish."

Machine-made.—Made by a machine; used in contra-distinction to hand-made.

Machinery.—A general term used collectively for a number of machines.

Supporting Machinery.—Machinery used in connection with the operation of a lift span.

Machinery Barge.—See "Barge."

Machinery House.—A house in which machinery is kept for its protection.

Machine Screw.—See "Screw."

Machine Shop.—See "Shop."

Machine Work.—See "Work."

Machinist Hammer.—See "Hammer."

Magnesian Lime.—See "Lime."

Magnesian Limestone.—See "Limestone."

Magnetic.—Having properties like those of a magnet—possessing magnetism.

Magnetic Needle.—See "Needle."

Main Diagonal.—See "Diagonal."

Main Member.—See "Member."

Main Shaft.—See "Shaft."

Main Stress.—See "Stress."

Maintenance Cost.—See "Cost."

Making Iron.—An iron with rounded teeth, used for driving home a strand of oakum.

Male Screw.—See "Screw."

Malleable.—Capable of being shaped by a beating or rolling process.

Malleable Cast Iron.—Same as "Malleable Iron." See "Iron."

Malleable Iron.—See "Iron."

Malleable Pig.—See "Pig."

Mallet.—A small wooden hammer wielded with one hand.

Calking Mallet.—A mallet used in driving calking irons.

Mallet Locomotive.—See "Locomotive."

Mandrel, or Mandril.—A short shaft of uniform or varying diameter upon which various pieces of metalwork can be mounted for turning in a lathe. A metallic core used in driving Raymond or Simplex piles.

Manganese.—A metal resembling iron and having a strong affinity for it. Used in the manufacture of all steels, the percentage thereof generally varying between one-half and unity.

Manganese Steel.—See "Steel."

Mangle.—A set of rolls for straightening plates.

Manheim Slide-rule.—See "Slide-rule."

Man-hole.—An opening or entrance by which a man can enter a closed space, such as a boiler, sewer, or conduit.

Manifold.—A tube, usually of cast metal, with one or more flanged or screw-threaded inlets and two or more flanged or screw-threaded outlets for pipe connections. To make a number of copies of anything by a single operation.

Manila Hemp.—See "Hemp."

Manila Rope.—See "Rope."

Man-power.—The power exerted by a man. A mechanism by which man can exert his power to advantage.

Map.—A descriptive drawing or delineation of a section of the country.

Hydrographic Map.—A map showing a watercourse or a portion thereof and indicating the depth of water at various points, the direction and velocity of the current, the character of bed and bank, and other information pertinent to any special stream.

Topographic Map.—A map showing the configuration of land by contour lines, or lines of equal elevation.

Margin.—A space along an edge or boundary line, a border.

Margin Draft.—See "Draft."

Marking Gauge.—Same as "Hand Gauge." See "Gauge."

Marline.—A small rope made of two strands loosely twisted together, used for winding around ropes, cables, etc.

Marline Spike.—See "Spike."

Masonry.—A general term applied to structures made of stone, brick, or concrete.

Ashlar Masonry.—Stone masonry composed of blocks cut to regular size, generally rectangular, laid in courses of uniform height.

Brick Masonry.—Masonry composed of brick, usually termed brickwork.

Broken-ashlar Masonry.—An ashlar masonry in which the bed joints are discontinuous at intervals, due to the use of smaller blocks of stone in making up the course.

Broken-range Masonry.—A range type of masonry in which the courses are not continuous throughout, due to their being made up at intervals of smaller blocks of stone.

Concrete Masonry.—Masonry composed of concrete. See "Concrete."

Crandalled Masonry.—Any type of masonry in which the stones have been dressed with a crandall. See "Dressing."

Cut-stone Masonry.—Any type of masonry composed of cut stone blocks having smoothly dressed beds and joints.

Doweled Masonry.—Masonry in which dowel pins are used to bind the several courses together and thereby prevent sliding.

Dry Masonry.—Masonry in which the stones are laid up without mortar.

First-class Masonry.—A term applied to quarry-faced ashlar, laid in regular horizontal courses, having parallel beds and vertical joints, of not less than ten inches in thickness nor more than thirty, and decreasing in thickness regularly from the bottom to the top of the wall. For complete specifications, see "Baker's Masonry."

Granite Masonry.—Masonry composed of granite blocks.

Green Masonry.—Masonry freshly laid, in which the mortar has not attained its full strength.

Random Masonry.—Masonry composed of blocks having squared joints, but of varying size and not laid in courses.

Masonry.

Range Masonry.—Masonry composed of blocks having squared joints and which are laid in courses varying in thickness.

Rubble Masonry.—Masonry composed of unsquared stone. It may be coursed or uncoursed rubble.

Second-class Masonry.—A term applied to broken range rubble of superior quality laid with horizontal beds and vertical joints on the face, with no stone less than eight inches thick, well bonded, and leveled as well as can be done without hammer dressing.

Small-ashlar Masonry.—Cut-stone masonry in which the stones are less than one foot thick.

Squared-range Masonry.—Masonry composed of squared stones laid in ranges or courses of varying thickness.

Squared-stone Masonry.—Masonry composed of stones roughly dressed and squared on beds and joints. Similar to ashlar masonry, but not having as close joints.

Third-class Masonry.—A term applied to rubble when of a good, substantial quality and laid in cement mortar.

Masonry Joint.—See "Joint."

Masonry Pier.—See "Pier."

Masonry Plate.—See "Plate."

Masonry Stone.—See "Stone."

Masonry Wall.—See "Wall."

Mason's Hammer.—See "Hammer."

Mass.—The quantity of matter in a body. It is measured by the ratio of its weight to the acceleration due to gravity.

Center of Mass.—That point at which the mass of a body may be considered as concentrated without disturbing its equilibrium; the center of gravity or the center of inertia of a body.

Mast.—An upright post of timber or steel, as the mast of a derrick.

Derrick Mast.—The upright member of a derrick, at the bottom of which the boom is attached and which is pivoted so as to allow the boom to swing either way.

Mastic.—A well-agitated mixture of several different small-grained constituents, one of which has a cementing or binding power.

Asphaltic Mastic.—A mastic composed of refined asphalt and other constituents, melted together at a temperature between 275° and 400° F., and thoroughly agitated by suitable appliances until the materials are completely blended into a homogeneous mass; sometimes referred to as Asphaltic Cement.

Mast Pin.—See "Pin."

Mast Seat.—The casting at the foot of a mast on which it rests and turns.

Mat.—Same as "Mattress," *q.v.*

Matching.—A fitting together of two or more parts.

Match Joint.—Same as "Tongue and Groove Joint." See "Joint."

Match-marking.—A system of marking the parts or members of a structure, so that they always may be connected up in exactly the same order and manner.

Material.—Any substance entering into the construction of a bridge.

Matrix.—A term used in connection with concrete to denote the cementing material which fills the voids of the aggregate.

Mattock.—A form of pick with broad cutting edges for digging.

Mattress.—A combination of willow poles and wire rope woven together, forming a mat which is placed on the bed or the bank of a stream to prevent scouring.

Mat Work.—See "Work."

Maul.—A type of large hammer or mallet having both ends flat for beating.

Housing Maul.—An iron maul heavier than a calking mallet.

Maul.

Knot Maul.—A wooden maul having a conical head made from a knot or other tough piece of timber.

Pin Maul.—A bridge erector's maul, having one end pointed with a long taper for entering rivet holes and the other end flat for hammering.

Spike Maul, or **Track Maul.**—A maul having one end long and tapering, used for driving railroad spikes.

Maximum Stress.—See "Stress."

Mayarí Steel.—See page 68.

Meager Lime.—See "Lime."

Meander Line.—See "Line."

Mechanical Curve.—Same as a "Transcendental Curve." See "Curve."

Mechanics.—The science of force and its effect upon matter. While the word was originally used to mean the theory of machines, it has, by extension, come to denote the doctrine of force and the resulting motions or tendencies to motion of particles and systems of particles. As such, it is the fundamental one of all the physical sciences.

Mechanism.—The structure of a machine, engine, or other contrivance for controlling or utilizing natural forces.

Medium Steel.—See "Steel."

Megohm.—An electrical unit of resistance equal to one million ohms. See "Ohm."

Melan Arch.—See "Arch."

Melt.—To fuse or liquify by applying heat. A term employed by blast-furnace men to denote the metal fused, or the charge or heat, as it is sometimes called.

Dead Melt.—In the fusion of metals, a condition of being fully or completely melted, and in which no gas is being evolved.

Melting-point.—The temperature at which a metal passes from the solid to the liquid state.

Melt-numbers.—The number given a heat or charge and carried by the product throughout the processes of rolling and fabrication.

Member.—A component part of a bridge or other structure, complete in itself.

Adjustable Member.—A member of a bridge, the length of which can be increased or diminished at will.

Main Member, or **Primary Member.**—A principal part of a truss or floor system—generally restricted to trusses.

Redundant Member.—A superfluous member. Its use is avoided as much as possible in the most approved American bridge-engineering practice.

Secondary Member.—A subordinate part of a bridge, as a lateral. Generally refers to the suspenders and sub-diagonals of trusses.

Secondary Truss-Member.—A subsidiary member used to support a main member, or to transfer a load from a mid-panel point to a panel point or panel points.

Tension Member.—A member of a structure subjected to tension only.

Truss Member.—Same as "Truss Element." See "Element."

Web Members.—The parts or sections forming the web of a truss. See "Web."

Merchants' Bar.—See "Bar."

Meridian Section.—See "Section."

Mesh.—An open space between the wires of a screen or sieve. Sometimes used to denote the netting composed of wires. Also used to denote the engaging of one gear with another.

Metacenter.—The point of intersection of a vertical line through the center of buoyancy and a line of symmetry through the center of gravity of a floating body.

Metal.—As used in bridgework, this term means steel, unless specifically stated otherwise.

Babbitt Metal.—An alloy of tin with copper and antimony, used for lining bearings and making bushings.

Metal.

Calking Metal.—A soft lead-rust mixture put in calking grooves. Sometimes Portland cement is used for such purpose.

Fatigue of Metals.—The doctrine which states that repetitions or reversals of stress, when excessive, cause a deterioration of the metal. Strictly speaking, it does not apply at all to bridgework.

Gun Metal.—Same as "Bronze," *q.v.*

Pin Metal.—The metal called for in the specifications, from which pins may be made.

Pot Metal.—A poor grade of cast iron.

Sterro Metal.—A brass containing from 1.77% to 4% of iron.

White Metal.—An alloy similar to Babbitt metal, but containing more antimony and copper.

Metal Lath.—See "Lath."

Metal Lathe.—See "Lathe."

Metallic Tape.—See "Tape."

Metal Saw.—See "Saw."

Meteoric Iron.—See "Iron."

Meter.—A unit of length in the metric system which equals 39.37 inches in the English and American systems. An apparatus for measuring quantities.

Current Meter.—An apparatus for measuring the velocities of flow in streams.

Water Meter.—An apparatus for measuring the quantity of water flowing in a pipe.

Metope.—A square slab, decorated or plain, inserted in the opening between adjoining ceiling beams.

Metric System.—A system of units of weights and measures depending upon the meter. It is the standard in Continental Europe and in Latin America, and ought to be adopted throughout the entire world.

Metric Ton.—See "Ton."

Micrometer.—An instrument for the precise measurement of small lengths and angles. The usual form consists of a screw with a very fine thread and a large graduated head.

Touch Micrometer.—A micrometer in which the final adjustment is determined by the sense of feeling.

Micrometer Calipers.—See "Calipers."

Micrometer Gauge.—Same as a "Micrometer Calipers." See "Calipers."

Micrometer-measurement.—A precise determination of the diameter of a test piece by a micrometer-screw.

Micrometer Screw.—Same as "Micrometer," *q.v.*

Middle-third.—A term in masonry construction used in connection with the line of pressure to denote a condition which must obtain in order to prevent tension at a joint of the structure; that is, the line of pressure must pass within the middle third of the section.

Mid-span.—The centre of a span.

Mikado Locomotive.—See "Locomotive."

Mild Steel.—See "Steel."

Mill.—A machine for rolling plates, shapes, rails, etc. The plant where steel shapes etc., are rolled. To remove metal by a circular tool having teeth as in a milling machine.

Boring Mill.—A large machine tool having a horizontal revolving table to which the object to be trimmed is fastened, and in which the cutting tool, except for feed adjustment, remains fixed in position while the object revolves. Used for turning large castings and boring large holes.

Cement Mill.—A factory where cement is manufactured.

Universal Mill.—A four-roll mill for rolling plates on both edges as well as on the faces.

Milled Lead.—Same as "Sheet Lead." See "Lead."

Milling.—The process of removing metal with a circular cutter in a milling machine.

Milling Machine.—A machine consisting of a rotating mandrel carrying a milling cutter, and a movable table, operated by a feed screw, to which is bolted the object to be milled.

Mineral Paint.—See "Paint."

Mirror Iron.—See "Iron."

Miter.—To cut at a bevel of forty-five degrees. A bevel of forty-five degrees.

Miter Gears.—See "Gears."

Miter Joint.—See "Joint."

Mixer.—A machine for mixing materials.

Concrete Batch Mixer.—A type of mixer in which the materials are placed in the desired proportions for a definite amount of concrete and then mixed and discharged before a fresh supply of materials is entered.

Concrete Continuous Mixer.—A type of mixer in which the materials are loaded into their respective hoppers and then mechanically discharged in small quantities at frequent and regular intervals into a common receptacle for mixing, from which the content is continually being forced into the discharging spout.

Modulus.—A number, coefficient, or quantity that measures a force, function, or effect.

Section Modulus.—See "Section Modulus."

Modulus of Crushing.—See "Crushing."

Modulus of Elasticity.—See "Elasticity."

Modulus of Rupture.—See "Rupture."

Mogul Locomotive.—See "Locomotive."

Molecule.—The smallest part into which any substance can be divided without destroying its chemical character.

Moment.—The tendency of a force to produce rotation or of a stress or mass-inertia to resist rotation. This tendency is measured by the product of the force into its lever arm.

Bending Moment.—The moment which produces or tends to produce bending in a beam or other member of a structure. It is measured by the algebraic sum of the products of all the forces by their respective lever arms.

Centre of Moments.—The point about which a body tends to rotate. Often a point arbitrarily chosen for convenience in determining the resultant moment of a system of forces.

Horizontal Moment.—A moment acting in a horizontal plane.

Negative Moment.—A relative term used to denote direction of rotation, usually taken counter-clockwise.

Overturning Moment.—The moment of the external forces tending to overturn a structure.

Positive Moment.—A moment acting in the opposite direction to a negative moment, or acting clockwise.

Resisting Moment.—The moment which opposes distortion, displacement, or overturning Sometimes loosely used for moment of resistance.

Righting Moment.—The moment that tends to right a floating body after displacement.

Theorem of Three Moments.—A theorem used in connection with continuous girders expressing the relation of the moment at any support to the moments at the preceding and following supports in terms of the loading and span lengths.

Twisting Moment.—Same as "Torque," *q.v.*

Virtual Moment.—See "Virtual."

Moment-area.—Same as "Area-moment." See "Area."

Moment-area Method.—The method for finding deflections in a framed structure by use of the moment area curve.

Moment Diagram.—See "Diagram."
Moment of a Couple.—See "Couple."
Moment of Inertia.—See "Inertia."
Moment of Resistance.—See "Resistance."
Moment of Stability.—See "Stability."
Moment of Torsion.—See "Torsion."
Momentum.—The quantity of motion in a body, measured by the product of its mass into its velocity.
Monier Arch.—See "Arch."
Monier-Construction.—A form of reinforced concrete in which wire netting is used for reinforcement.
Monkey.—An early type of pile-driver hammer.
Monkey Engine.—See "Engine."
Monkey Pile Driver.—See "Pile Driver."
Monkey Wrench.—See "Wrench."
Mooring.—A fastening; that to which anything is fastened.
Mortar.—A mixture of cement or lime with sand and water forming a thick paste, used in masonry work for bedding the stones and filling the joints.
Blowing of Mortar.—Mortar placed by compressed air forcing it through a pipe or nozzle.
Cement Mortar.—A mortar made from cement.
Hydraulic Mortar.—Mortar made of hydraulic cement, so that it will set under water.
Lime Cement Mortar.—A mortar in which lime and cement are used together. Not a proper mixture for bridge construction, the only reason for its use being to reduce first cost, which it invariably does at the expense of the effectiveness of the construction.
Lime Mortar.—A mortar made from lime. Should never be used in bridgework.
Retempering Mortar.—The wetting and stirring up of mortar after partial setting. A most reprehensible practice.
Tempering Mortar.—The mixing and working of mortar to secure a uniformly plastic condition.
Mortar-board.—A platform on which mortar is mixed.
Mortar-box.—See "Box."
Mortise.—The slot or hole cut in a timber to receive the tenon.
Mortised Joint.—See "Joint."
Motor.—A machine for producing or translating power.
Electric Motor.—A motor run by an electric current.
Motor Bridge.—See "Bridge."
Motorway.—The passageway on a bridge used by motor cars.
Mottled Iron.—See "Iron."
Mould.—A form or model pattern of a particular shape, used in fixing the shape of a plastic mass. Sometimes spelled "Mold."
Briquette Mould.—A standard form used for making briquettes out of mortar.
Cement Mould.—A mould used in forming cement mortar for testing purposes.
Ingot Mould.—A flask in which metal is cast into a large block or ingot.
Moulded Gear.—Same as "Cast Gear," *q.v.*
Moulding.—The process of shaping a plastic substance into a given form by the use of moulds. Also a decorative member in construction.
Moulding Planks.—See "Planks."
Mountain Locomotive.—See "Locomotive."
Mousing.—A string or wire wound around the end of a rope to prevent raveling.
Movable Bridge.—More correctly speaking, a movable span. See "Span."
Movable Cofferdam.—See "Cofferdam."
Movable Span.—See "Span."

Moving Load.—See "Load."
Muck.—Soft mud containing vegetable matter.
Muck Bar.—See "Bar."
Mucking.—Excavating or working in muck.
Muck Iron.—See "Iron."
Mud Line.—The line of intersection of the mud surface with any object.
Mud Pump.—See "Pump."
Mud Sill.—See "Sill."
Muffler.—A device to prevent the noise of steam or gas when escaping from an exhaust pipe.
Mule Traveler.—See "Traveler."
Multicentered Arch.—See "Arch."
Multiple Cancellation.—See "Cancellation."
Multiple Intersection.—Same as "Multiple Cancellation." See "Cancellation."
Multiple Punch.—See "Punch."
Multiple System.—A truss system having more than one system and usually more than two systems of cancellation.
Multiple Truss.—See "Truss."
Murphy Truss.—See "Truss."
Mushet Steel.—A steel produced by the Mushet process of recarburization, which consists of adding spiegel or other form of manganese.
Mushroom Anchor.—See "Anchor."
Mushy.—The condition of a casting containing an excessive number of blow holes rendering it unsound.

N

Nail.—A slender piece of metal either pointed or tapering, used for driving through wood or other material. Nails run in size from 2d (two penny), one inch long, to 20d (twenty penny), four inches long in carpenter usage. Bridgemen use nails up to 60d (sixty penny), or six inches long, after that they are classed as spikes.
  Calking Nail.—A pointed hand-tool used in metal calking.
  Cut Nail.—A nail which is cut from a plate.
  Wire Nail.—A nail made from wire.
  Wrought Nail.—A nail hammered out from a bar.
Nail-extractor.—A hand-tool for pulling nails.
Nail-head Spike.—See "Spike."
Nailing-blocks.—Blocks of wood inserted in walls of stone, brick, or concrete for nailing boards to.
Name Plate.—See "Plate."
Naperian Logarithm.—See "Logarithm."
Nasmyth's Steam Hammer.—See "Hammer."
Natural Bar.—See "Bar."
Natural Bed.—See "Bed."
Natural Cement.—See "Cement."
Natural Logarithm.—See "Logarithm."
Natural Scale.—See "Scale."
Nave.—The hub of a wheel.
Neat.—Pure; undiluted; unadulterated. Also sometimes used for net, *q.v.*
Neat Briquettes.—Same as "Cement Briquettes," *q.v.*
Neat Cement.—See "Cement."
Neat Lime.—See "Lime."
Neat Line.—See "Line."
Neat Work.—See "Work."

Neck.—That part of a test specimen, subjected to tension, which shows a reduction of area of cross-section when the ultimate load is reached. To reduce suddenly the sectional area of a piece of metal. To nick.

Necking-down.—The act of reducing the cross-section of a test specimen by stressing it beyond the yield point.

Neck Journal.—See "Journal."

Needle.—A very small steel rod or bar.

Cement Needle.—A small round rod weighted with a ball, used to determine the activity of cement.

Magnetic Needle.—A thin, small bar of magnetized steel used in a surveyor's compass to determine the magnetic meridian at any place.

Vicat Needle.—A small rod, one millimeter in diameter, mounted in a frame and bearing a weight of three hundred grams; used for testing the activity of cement.

Needle Beam.—See "Beam."

Negative Moment.—See "Moment."

Negative Print.—See "Print."

Negative Reaction.—See "Reaction."

Negative Rotation.—See "Rotation."

Negative Shear.—See "Shear."

Nest (of rollers).—A group of rollers, enclosed in a suitable frame or box, which support a bridge shoe.

Net.—Clear of anything extraneous. Lowest or smallest. Not subject to any further deduction or correction. Netting.

Netting.—A wire mesh-work used somewhat in reinforced-concrete construction, especially for piling.

Net Section.—See "Section."

Neutral Axis.—See "Axis."

Neutral Curve.—See "Curve."

Newel Post.—See "Post."

New York Rod.—A type of level rod. See "Rod."

Nickel Steel.—See "Steel."

Nidging or **Nigging.**—A form of stone dressing. See "Dressing."

Niggerhead.—A spool on the end of the axle of a hoisting engine.

Night Foreman.—See "Foreman."

Night Superintendent.—See "Superintendent."

Nipper.—A block which slides in the leads of a pile driver and carries a pair of hooks or tongs for picking up the hammer below it.

Nipper Pile Driver.—See "Pile Driver."

Nipple.—A short piece of pipe threaded throughout its entire length.

Nodule.—A small lump.

Nog.—Same as "Free-nail," *q.v.*

Nominal Horsepower.—Same as "Commercial Horsepower." See "Horsepower."

Non-concurrent.—Applied to non-parallel forces not having a common point of intersection.

Non-fusibility.—The ability to resist fusing.

Non-volatile Thinner.—See "Thinner."

Non-volatile Vehicle.—See "Vehicle."

Normal Stress.—See "Stress."

Norway Iron.—See "Iron."

Norway Pine.—See "Pine."

Nose.—A pointed or tapering projection in front of an object., *e.g.*, the nose of a pier that acts as an ice-break.

Nosing.—The end of a pier. See "Starling." The projection on the front edge of a step.

Notching.—Cutting into a timber so that it will fit over another. Nicking.

Nozzle or **Nozle.**—A short pipe or tube with a contracted opening.

Jet Nozzle.—The contracted and perforated portion at the bottom of a jet pipe.

Nurick Column.—See "Column."

Nut.—A short prism of metal having a central hole which is threaded to receive a bolt or a screw.

Beam Hanger Nuts.—The nuts on the ends of beam hangers, serving to press the floor-beam against the feet of the posts or against the chord-heads.

Check Nut.—An extra nut which is screwed on a bolt tight against the first nut to prevent the latter from working loose.

Driving Nut.—A special, flat-headed, hollow, round nut temporarily screwed on one end of a pin to receive the blows of the hammer or ram during the driving of the pin home.

Hexagonal Nut.—A nut having six equal sides in the form of a regular hexagon.

Jam Nut.—Same as "Check Nut," *q.v.*

Left-handed Nut.—A nut having a left hand thread.

Lock Nut.—A nut having some special provision to prevent turning.

Lomas Nut.—A nut having a recess on the bottom which permits it to be screwed down on the pin until the edges of the nut bear on the eye-bars packed on the said pin.

Pilot Nut.—A round nut, having one end tapering, which is screwed on a pin in order that it may be pushed through the eyes of the several eye-bars and other members meeting at a panel point. After the pin is in place, the pilot nut is removed, and a Lomas nut is screwed on in its place.

Pin Nut.—A special flat nut used on truss pins.

Right-handed Nut.—A nut having a right-hand thread.

Sleeve Nut.—A sleeve having a right-hand thread at one end and a left-hand one at the other.

Square Nut.—A nut having four sides in the form of a square.

Thumb Nut.—A nut having a flat projection, or wings, so that it can be turned by the thumb and finger.

U-Nut.—A piece of iron or steel in the shape of a letter U, through which passes the threaded end of a rod, and which affords a bearing for the nut, with room to screw up the latter. Its use is not permissible in first-class bridge construction.

Wing Nut.—Same as "Thumb Nut," *q.v.*

Nut-cracker.—A tool for breaking the nuts on rusty bolts.

Nut Lock.—See "Lock."

O

Oakum.—The coarse part of flax or hemp separated in hackling; also old ropes untwisted and picked into loose fibres resembling tow; used for calking the seams of vessels and caissons.

Oblique Arch.—See "Arch."

Oblique Crossing.—See "Crossing."

Ochre.—A term applied to a class of natural earths consisting of mixtures of the hydrated sesquioxide of iron with various earthy materials, principally silica and alumina. Many of these earths are used for pigments in paints.

Red Ochre.—A variety of ochre having a red color, used for paint.

Yellow Ochre.—A variety of ochre having a yellow color, used for paint.

Octagon.—A regular eight-sided polygon.

Odometer.—An instrument for measuring distance by running a wheel over the course. The circumference of the wheel is accurately determined and a counting device attached so as to register the number of revolutions.

Offset.—A short line run at right angles to a principal, or base, line. To move over from a base line to an auxiliary line called an offset line.

Ogee Curve.—See "Curve."

Ogee Washer.—See "Washer."

Ohm.—The unit of electrical resistance; approximately the resistance of one thousand feet of No. 10 B. & S. copper wire.

Oil Bearing.—See "Bearing."

Oil Boxes.—See "Boxes."

Oil Can.—A can having a long tapering spout, used for pouring oil into bearings.

Oil Groove.—See "Groove."

Oil Hardening.—The process of quenching red-hot steel in oil in order to harden it.

Oil-hole.—A hole drilled in the cap of a bearing for pouring oil through.

Oil-stone.—A slab of fine-grained stone used for sharpening tools by rubbing them on its oiled surface.

Oil Tempering.—See "Tempering."

Old English Bond.—See "Bond."

Old-man.—An iron frame bent into the form of a U having hooks on the ends so that it can be hung to a bar, a rail, or the flange of a girder and used to form a bearing for a ratchet drill or reamer.

One Hinged Arch.—See "Arch."

One-man Stone.—A rough classification for stone of a size that can be readily lifted and put into place by one man. Used to reduce the cost of concrete.

Oölitic Limestone.—See "Limestone."

Opacity.—The degree of obstruction to the transmission of visible rays. Used in connection with paint.

Open Caisson.—See "Caisson."

Open Crib.—See "Crib."

Open-dredging.—A process of sinking piers by excavating with a dredge through an open crib.

Open-end Wrench.—See "Wrench."

Open Hearth.—The hearth of a metallurgical furnace which is exposed to the direct action of the flame.

Open-hearth Furnace.—See "Furnace."

Open-hearth Process.—A process for the production of steel by the oxidation and removal of the impurities contained in a bath of metallic iron lying on the hearth of a regenerative furnace.

Acid Open-hearth Process.—That process of producing steel from pig and scrap iron, in which the first step is to remove most of the silicon, manganese, and carbon from the molten mass. Just before tapping, spiegeleisen or an artificial ferromanganese is added to the charge in order to destroy the oxide slag and prevent red shortness. The furnace is lined with a silicious material.

Basic Open-hearth Process.—That process of producing steel from pig and scrap iron, in which the first step is to remove the phosphorus and some of the sulphur as well as the silicon, manganese, and carbon. This is accomplished by charging the furnace with calcined lime, which unites with the excess phosphorus and holds it in the slag. The rest of the process is similar to the acid open-hearth process. To prevent the slag from attacking the lining, the furnace is covered with dolomitic limestone. Such furnaces are termed basic lined, and the process has become known as the basic open-hearth process because of this lining.

Open-hearth Steel.—See "Steel."

Open Holes.—Rivet holes in members and connections left open during fabrication to enable the erector to connect the parts in the field, after which field rivets are driven into them.

Open Joint.—See "Joint."

Open Web.—See "Web."
Open-webbed Girder.—Same as "Latticed Girder." See "Girder."
Operating House.—A bridge-tender's house from which the operation of the draw-span is controlled.
Operation Cost.—See "Cost."
Orange-peel Bucket.—See "Bucket."
Orange-peel Dredge.—See "Dredge."
Order Bill.—A form of bill used in ordering material from the manufacturers.
Ordinate.—One of the coordinates in a system of rectangular coordinates defining the position of a point.
Ore Bridge.—A gantry crane used for handling ore at a blast furnace. See "Crane."
Origin of Coordinates.—See "Coordinates."
Ornamental Work.—See "Work."
Ornamentation.—A general term for the entire ornamental work on a structure.
Oscillation.—A vibratory movement of any body of appreciable size.
Outer Guard-rail.—See "Guard-rail."
Outer Hip.—See "Hip."
Outhaul.—A method used by erectors for assembling a member which is beyond the reach of the boom of the derrick. It consists in placing a pulley block ahead of the member beyond the derrick and doubling back the lead line to the hoisting engine.
Outline.—The exterior line defining the shape of a body.
Out of Gear.—A condition in a system of mechanism when the driving gear does not mesh with the driven gear and, in consequence, no motion is transferred.
Out of Square.—Askew, oblique.
Out of Wind.—Free from twist; not warped.
Output.—The production of a mill, plant, or company for a certain period.
Outrigger.—A beam or joist projecting from a structure, used to support a load at its end.
Outrigger Hoist.—See "Hoist."
Outside Calipers.—See "Calipers."
Outside Lock Tender.—See "Tender."
Outside Stringers.—See "Stringer."
Oval.—A closed curve, everywhere convex, without nodes or cusps and having sharper curvature at one end than at the other.
Overblown.—A term applied to Bessemer steel which has been blown too long and is overoxidized and hence inclined to be wild.
Overhang Knot.—See "Knot."
Overhaul.—The excess haul or movement of earth or rock beyond a specified distance named in the contract. To examine thoroughly with a view to repairs. To take up slack in a rope by pulling thereon.
Overhead Balanced Crane.—See "Crane."
Overhead Bracing.—See "Bracing."
Overhead Crane.—See "Crane."
Overhead Crossing.—See "Crossing."
Overhead Girder.—See "Girder."
Overhead Strut.—See "Strut."
Overheat.—To heat metal to a temperature near the melting point, causing it to become coarse grained and reducing the cohesion between the particles.
Overlap.—To extend over and rest upon; to fold over.
Overlapping Joint.—See "Joint."
Overload.—See "Load."
Overmelt.—To keep steel too long in a state of fusion.
Overtime.—The excess time over the regular schedule of hours which a workman labors.
Overturning Moment.—See "Moment."

Ovolo.—A projecting convex moulding of a quarter of a circle in section.

Oxide of Iron.—Same as "Iron Oxide," *q.v.* Also see "Ochre."

P

Pacific Type Locomotive.—See "Locomotive."

Pack.—To arrange eye-bars on a truss pin. To insert some pliable or elastic material in a stuffing box around a moving rod so as to produce a water-tight, air-tight, or steam-tight connection.

Packing.—The arrangement of the component parts of a member. The material used in packing a piston rod, etc. The arrangement of bars and other members on a pin.

Asbestos Packing.—Packing made from asbestos fibre and put up in the form of wicking.

Candle-wick Packing.—A packing made of cotton fibres and put up in the form of a loosely-woven cord.

Chord Packing.—The arrangement of all the members of a pin-connected chord.

Hemp Packing.—Packing made of hemp fibres and put up in the form of a soft, loosely-woven rope.

Journal Packing.—Waste, cotton, or other fibrous material saturated with oil or grease and placed in a journal box to lubricate the axle.

Jute Packing.—Packing made of jute fibres and put up in the form of a soft, loosely-woven rope.

Rubber Packing.—Packing made of rubber, usually with cloth backing or insertions. Put up in sheet form or in flexible bars.

Sheet Packing.—Any packing put up in the form of thin layers.

String Packing.—Any packing put up in the form of cords.

Stringer Packing.—The arrangement of stringers under a track on a trestle.

Wick Packing.—Any packing put up in the form of wicks.

Packing-block.—A small member, generally of wood, used to retain the parts of a composite member in their proper relative positions.

Packing Bolt.—See "Bolt."

Packing Box.—Same as "Stuffing Box." See "Box."

Packing Diagram.—See "Diagram."

Packing-pieces.—Short pieces, inserted between two others which are riveted or bolted together, to prevent their coming in contact with each other.

Packing Ring.—See "Ring."

Packing Spool.—Same as "Separator," *q.v.*

Packing Washer.—See "Washer."

Pæane Hammer.—Same as "Peen Hammer." See "Hammer."

Paint.—A mixture of pigment with a vehicle intended to be spread in thin coats on a surface for its protection, or its decoration, or both.

Graphite Paint.—A paint in which graphite is used for the pigment.

Mineral Paint.—Any paint in which a mineral pigment is used.

Water-proof Paint.—Any paint not soluble in water.

Paint-brush.—Any brush used for applying paint.

Painter's-torch.—A torch burning gasoline or gas under pressure produced by forcing air into the reservoir. Used for burning off old paint.

Paint-skins.—The residue in paint formed by the evaporation of the oil. Used for filling small voids in metalwork before applying the paint.

Pale Brick.—See "Brick."

Pall.—A dog in a ratchet for preventing backward motion.

Pallet.—A board on which green bricks are carried to the drying place. A cast-iron tool with chilled faces; used in forging. Also same as "Pall," *q.v.*

Palmer Truss.—See "Truss."

Pane Hammer.—Same as "Peen Hammer." See "Hammer."

Panel.—That portion of a truss between adjacent panel-points lying in the same chord.

Subdivided Panel.—A panel divided by a sub-diagonal or hanger.

Tower Panel.—The longitudinal space or bay in a trestle or viaduct occupied by the tower.

Panel Length.—See "Length."

Panel Load.—Same as "Apex Load." See "Load."

Panel-point.—The point at which the axis of a principal web member intersects the axis of a chord of a truss.

Pannikins.—Small pans or cups.

Pantograph.—An instrument for the mechanical copying of engravings, diagrams, plans, etc., either to an enlarged or to a reduced scale. It consists essentially of four sticks pivoted so as to form a parallelogram with a fixed pivot at one end of the group, a tracing point at the other end, and a pencil at the intermediate apex.

Paper.—A material composed of vegetable fibres made into thin sheets, used to write or draw on, etc.

Asbestos Paper.—A paper made from asbestos fibre.

Blue Print Paper.—A paper coated on one side with a preparation of potassium ferrocyanide which is sensitive to light. It is used for copying maps, plans, etc.

Calculation Paper.—A paper with quadrille ruling used by computers, because of its convenience in drawing sketches and in arranging computations in a tabular form.

Cold-pressed Paper.—A drawing paper that has been pressed only on the felts, leaving it with a rough surface.

Coordinate Paper.—Paper ruled into small squares with every tenth line accentuated, for convenience in counting or in tracing a line.

Cross-section Paper.—A standard quadrille-ruled paper in which the principal squares are one inch on a side and the secondary squares are one-tenth of an inch on the side.

Detail Paper.—A tough paper used for pencil drawings.

Egg-shell Paper.—A heavy drawing paper having a finish on one side resembling the surface of an egg-shell.

Hot-pressed Paper.—A variety of drawing paper polished by pressure between heated plates.

Profile Paper.—A standard, double-ruled paper in which the scale in one direction is a multiple, usually five, of the scale in the other.

Tarred Paper.—A paper saturated or coated with tar.

Tracing Paper.—A thin, tough, translucent paper used for tracing drawings.

Whatman's Paper.—A trade name for a well-known brand of drawing paper manufactured by the Whatman Turkey Mills.

Parabola.—A plane curve such that the distance of every point in it from a fixed point, called the focus, is equal to the distance of the same point from a fixed straight line, called the directrix. Also the curve formed by the intersection of a secant plane with a cone when parallel to an element of the said cone. Also defined by the equation $y^2 = 2px$.

Parabolic Chord.—See "Chord."

Parabolic Formula.—Any formula having the form of $y^2 = 2px$.

Parabolic Truss.—See "Truss."

Paraffine.—A whitish, waxy substance obtained by the dry distillation of wood, peat, bituminous coal, wax, crude petroleum, etc. A saturated hydrocarbon derived from methane.

Parallel.—A condition of being everywhere equidistant, not intersecting. Applied to lines and planes.

Parallelogram.—A four-sided geometrical figure having the opposite sides parallel and equal.

Parallelogram of Forces.—A name given to a method of determining the resultant of two forces, acting in the same plane, by constructing a parallelogram having sides equal and parallel respectively to the forces; whereupon, the diagonal of the parallelogram will represent in magnitude and direction their resultant.

Parallelopiped.—A prism having parallelograms for bases.

Parallel-ruler.—A draftsman's instrument for drawing parallel lines, consisting of two similar rulers connected by equal, parallel links pivoted at their ends, enabling the edges of the rulers to be spread apart a varying distance.

Parapet or **Parapet Wall.**—A low wall or barrier placed on top of an abutment to hold back the earth from encroaching on the end of the span.

Parcel.—To wrap canvass or rags around a rope.

Parker Cement.—See "Cement."

Parker Truss.—See "Truss."

Partial Splice.—See "Splice."

Parting Pulley.—Same as a "Split Pulley." See "Pulley."

Party of the First Part.—A legal term for designating one of the parties executing a contract, usually the purchaser.

Party of the Second Part.—A legal term for designating one of the parties executing a contract, usually the seller.

Passenger Locomotive.—See "Locomotive."

Passometer.—An instrument for registering the number of steps taken by a pedestrian. Called also a "pedometer."

Paste Lime.—See "Lime."

Pat.—A small, flat cake of cement mortar with the edges thinned out; used in cement testing to determine its soundness or freedom from cracking.

Patent Hammer.—See "Hammer."

Patent Hammer Dressing.—See "Dressing."

Patten.—The base of a column or pillar. The sole for the foundation of a wall.

Pattern.—A model made of wood to duplicate the desired object. It is used to form the cavity in a mould into which the molten metal is afterward poured.

Pattern Shop.—See "Shop."

Pavement.—A surface covering for a roadway.

Paving.—Regularly placed stone, brick, or wood blocks forming a floor.

Paving Brick.—See "Brick."

Pawl.—A short bar pivoted at one end and engaging a toothed wheel at the other, thereby preventing a backward rotation. Also spelled "Pall," *q.v.*

Pay.—To cover a surface with tar or pitch, etc.

Pay-out.—To slacken or let out rope.

Peak.—A projecting point; a cusp in a curve.

Pean Hammer.—See "Hammer."

Pean Hammer Dressing.—See "Dressing."

Peavey.—A form of cant-hook with a spike in the end of the handle next to the hook; used by timber men.

Pecky Tie.—See "Tie."

Pedestal.—A footing for a tower post. A bridge shoe, *q.v.*

Pedestal Block.—Same as "Base Casting." See "Casting."

Pedestal Cap.—See "Cap."

Pedestal Pier.—See "Pier."

Pedestal Pile.—See "Pile."

Pedestal Strut.—See "Strut."

Pedestrian-way.—That part of a bridge floor set aside for pedestrians. A footwalk.

Pediment.—The triangular space in the face of a wall that is included between the two sloping sides of the roof and a line joining the eaves.

Pedometer.—An instrument for numbering the paces of a person walking and thereby permitting an estimate to be made of the distance covered. Called also a "Passometer."

Peen.—A form of hammer head or similar tool which terminates in some special shape, other than the ordinary flat face; such as an edge shape or rounded, or a cone-shaped, hemispherical, or otherwise modified point. To treat by striking regularly all over with the peen of a hammer. Also spelled "Pane," "Pean," "Pæane," "Pein" and "Pene."

Peen Hammer.—See "Hammer."

Peg.—A term sometimes used for a surveyor's stake. A small stick driven flush or nearly flush with the ground, to hold the rod upon when levelling. To fasten anything to the ground with pegs.

Pegram Truss.—See "Truss."

Pein Hammer.—Same as "Peen Hammer." See "Hammer."

Pendulum.—Anything that hangs down from a point of attachment and is free to swing.

Pendulum Pile Driver.—See "Pile Driver."

Pendulum Saw.—See "Saw."

Pene.—Same as "Peen," *q.v.*

Pene Hammer.—Same as "Peen Hammer." See "Hammer."

Penetration.—A term used in connection with piles to denote the depth to which a pile has been driven in the soil. Also used in connection with the testing of asphalts and asphaltic fluxes to determine viscosity. It is expressed in hundredths of a centimeter to which a standard needle penetrates the material.

Pennsylvania Truss.—See "Truss."

Per Cent of Heart.—See "Heart."

Perch.—A stone mason's unit of quantity varying in value from 16½ cubic feet to 24¾ cubic feet, depending upon local usage. The use of this unit should be discouraged as far as possible, as its indefiniteness leads to uncertainty and confusion.

Percolation.—The process of straining or filtering a substance. The passing of water or other fluid through the pores of a solid.

Percussion.—The act of striking one body against another; the shock produced by collision.

Centre of Percussion.—That point of a suspended body such that if a blow be struck thereon no reaction will be developed at the point of suspension. This point is identical with the centre of oscillation and is located at such a distance from the point of suspension that if the whole mass of the body were concentrated there, the time of oscillation would remain unchanged.

Percussion Cap.—See "Cap."

Percussion Drill.—See "Drill."

Percussion Fuse.—See "Fuse."

Perimeter.—The outer boundary of a figure.

Periodic Curve.—See "Curve."

Periodic Deposit.—A payment made at regular intervals to a sinking fund.

Period of Vibration.—See "Vibration."

Periphery.—The boundary line of a closed figure, same as "Perimeter," *q.v.*

Periphery Lines.—See "Line."

Permanent Set.—Same as "Hard Set." See "Set."

Permeability.—The quality or condition of being permeable, or capable of being traversed by liquids or gases.

Perspective.—The art of representing solid objects on a flat surface so that, when they are viewed, the eye is affected in the same manner as it would be by viewing the objects themselves from a given point.

Centre of Perspective.—The point which is collinear with every pair of corresponding points of two figures in perspective.

Perspective Drawing.—See "Drawing."

Pestle.—A rounded, pear-shaped tool with a handle, used for the grinding and pulverizing of materials in a mortar.

Pet Cock.—See "Cock."

Petit Truss.—See "Truss."

Philadelphia Rod.—See "Rod."

Phœnix Column.—See "Column."

Phosphor-bronze.—An alloy of copper and tin containing from one-half to one per cent of phosphorus. It makes hard castings and has an ultimate tensile strength varying from 50,000 to 100,000 pounds per square inch.

Phosphorus.—A chemical element having a strong affinity for oxygen, encountered as an impurity in iron ores. Its presence causes cold shortness in steel.

Pick.—A hand-tool for excavating hard soils, consisting of a heavy curved bar, having one end pointed and the other wedge-shaped, and having a hole in the enlarged central portion for the insertion of a handle.

Pick Axe.—See "Axe."

Picked Dressing.—A type of stone dressing. See "Dressing."

Pickling.—The treatment of iron or steel with dilute acids for the purpose of obtaining a clean surface by removing the scale (oxide).

Pick-pole.—A small pike pole without the hook.

Pick-up Bar.—See "Bar."

Picture Drawing.—See "Drawing."

Pier.—A structure, usually composed of masonry, which is used to transmit the loads from a bridge superstructure to the foundation.

Anchor Pier.—A pier used in cantilever bridges to resist the uplift at the end of the anchor arm.

Battered Pier.—A pier having its sides slightly inclined to the vertical, giving a larger section at the base than at the top.

Brick Pier.—Any pier made of bricks.

Buried Pier.—A small secondary pier built a short distance from the main shore pier and carrying the end of an approach span. It takes the place of an abutment and is more economical, as it has no wing-walls and does not have to resist the lateral pressure of the earth, because the embankment spills around it on all sides.

Concrete Pier.—A pier made of concrete.

Cylinder Pier.—A pier made of a cylindrical steel shell filled with concrete.

Dumb-bell Pier.—A pier composed of two cylindrical piers connected by a solid web.

Floating Pier.—A term applied to a pier sunk to a great depth in a soft, yielding, or semi-fluid soil and depending for stability on the principle of flotation.

Masonry Pier.—A pier constructed of stone masonry.

Pedestal Pier.—A combination of two pedestals on a common base, but having separate tops.

Pile Pier.—A pier formed by driving a cluster of piles and capping them with heavy timbers in the form of a grillage to carry the shoes of the span.

Pivot Pier.—The pier supporting a swing span and upon which it turns.

Pneumatic Pier.—A pier sunk by the pneumatic process.

Rest Pier.—A pier which supports one of the ends of a draw span.

Submerged Pier.—A pier entirely below the water line.

Timber Pier.—A pier constructed of timbers, usually in conjunction with piles.

Piercing.—Producing a hole in a body by forcing a pointed instrument through it, the displaced material being forced into the body. Distinct from punching.

Pier Footing.—See "Footing."

Pierre-perdue.—Lost stone. Rough stones thrown into the water and left to find their own slope. Used for pier and wharf protection.

Pig.—The name given to cast iron which is drawn direct from the blast furnace and run, for convenience of later handling and transporting, into shapes known as pigs.

Basic Pig.—Pig iron used in making basic open-hearth steel in which the silicon content is limited to one per cent and the sulphur to one-half of one per cent.

Bessemer Pig.—Pig iron used in making Bessemer steel or acid open-hearth steel, in which the silicon content ranges from one per cent to two per cent; phosphorus not over one-tenth of one per cent; and sulphur not over one-half of one per cent.

Cinder Pig.—A pig iron made from smelting top cinder or bulldog with ores.

Forge Pig.—An inferior grade of iron used for puddling and for some classes of foundry work.

Foundry Pig.—Pig iron used in foundry castings.

Malleable Pig.—Pig iron used for making malleable castings.

Pig Iron.—Same as "Pig," *q.v.*

Pigment.—The fine, solid particles used in the preparation of paint, and substantially insoluble in the vehicle.

Pig-washing.—A process of refining or removing much of the phosphorus and silicon, in which the molten pig iron is treated with fused oxides of iron (and in some cases is mixed with oxides of manganese) in a reverberatory furnace.

Pike-pole.—A long, slender hand-pole with a steel point and hook at one end, used for handling timber.

Pilaster.—A thin, flat projection from the face of a wall made to resemble a column, for ornamental purposes.

Pile.—A long, heavy post or pole of timber, concrete, or steel driven into the ground to compact the soil, to shut out water, to carry a vertical load, or to resist a horizontal force.

Anchor Pile.—A pile used for the attachment of lines for anchorage purposes.

Batter Pile or **Battered Pile.**—A pile driven at an inclination to the vertical.

Bearing Pile.—Any pile carrying a vertical load.

Built Pile.—A pile made up of several parts.

Cement Pile.—Same as "Concrete Pile," *q.v.*

Charred Pile.—A wooden pile having its lower end charred in order to preserve it.

Chenoweth Pile.—A rolled concrete pile designed by a Mr. Chenoweth.

Club-footed Pile.—Same as "Pedestal Pile," *q.v.*

Closing Pile.—The last pile driven for closing a gap.

Columnar Pile.—A pile in which the bearing capacity, due to its point striking a hard stratum, depends chiefly on its action as a column.

Concrete Pile.—A pile made of concrete.

Corrugated Pile.—A precast, tapered, concrete pile with semi-cylindrical flutes running lengthwise, having reinforcing rods, and a two-inch hole in the centre for a jet.

Cushing Pile.—A square timber pile driven in a group in which all the piles are practically in contact. This method of pile foundation is now obsolete.

Disk Pile.—A steel pile with a disk at the bottom for increasing the bearing area. It is used in soft sandy soils and requires the employment of a water-jet in sinking.

Falsework Pile.—A pile driven temporarily as a part of the falsework used during the erection of a span.

Fender Pile.—A pile which is driven at wharfs, or in front of large masonry structures or other important works, to protect them from sudden blows by vessels.

Filling Pile.—A form of concrete pile made by first forming a hole in the ground with a mandrel and, after withdrawing it, filling the hole with concrete.

Foundation Pile.—A pile used permanently in the foundation of a pier.

Gauge Pile.—Ordinary piles, driven at intervals of about ten feet, to which are attached wales or runners against which are driven the sheet piles for a cofferdam.

Gilbreth Pile.—A corrugated reinforced concrete pile designed by a Mr. Gilbreth.

Pile.

Guide Pile.—A pile driven near a caisson to act as a guide during sinking.

Hollow Pile.—A shell driven into the ground to receive concrete.

Jetted Pile.—Any pile that has been sunk by means of a jet.

Key Pile.—The principal pile in a group of piles.

Lagged Pile.—A pile having four or more long longitudinal timbers bolted to its sides for the purpose of increasing the area exposed to skin friction, and thereby obtaining an increased bearing capacity.

Leading Pile.—A pile at the head of a row of piles.

MacArthur Pile.—Same as "Pedestal Pile," *q.v.*

Mooring Piles.—Piles used for fastening boats and barges.

Pedestal Pile.—A patented pile formed by driving a steel shell into the ground to the required depth, putting in small quantities of concrete, and hammering them down so as to force the concrete into the earth beyond the point of the shell; thus enlarging the end and greatly increasing the bearing area. The shell is afterward withdrawn gradually, as the hole that it made is filled with concrete. If the shell were left in, the method would be far more satisfactory; as the shaft of the pile is liable to be seriously imperfect. Sometimes dubbed a club-footed pile.

Penetration of Pile.—Same as "Penetration."

Plank Pile.—A pile built of planks.

Plumb Pile.—A pile driven vertically, usually one of the inside piles of a bent.

Pneumatic Pile.—A small diameter steel cylinder sunk by the pneumatic process.

Precast Pile or **Premoulded Pile.**—A form of concrete pile made in a mould and allowed to harden or season before being driven.

Raymond Pile.—A form of filling pile in which a steel shell is driven into the ground and allowed to remain, at the time of withdrawing the mandrel, so as to form a lining for the hole into which the concrete is poured.

Refusal of Pile.—That condition in pile driving when further driving fails to increase the penetration.

Rolled Pile.—A type of concrete pile in which concrete is rolled up in a wire mesh, to which longitudinal reinforcing rods are attached. The mesh takes the form of a spiral during the process, which is continued until the desired size and shape are secured.

Round Pile.—A pile having a round cross-section.

Sand Pile.—A pile made by forming a hole in the ground and filling the same with sand thoroughly tamped.

Screw Pile.—A steel pile similar to a disk pile but having a portion of a helicoid at its point so as to enable the pile to be screwed into place.

Sheet Pile.—A form of piling used to shut out water, generally made of several planks spiked or bolted together, and arranged to secure a tongued and grooved effect when driven close together. Steel shapes are also employed for this purpose.

Simplex Pile.—A type of filling pile made by driving a steel shell, having a steel point, into the ground and filling same with concrete while the shell is being withdrawn.

Spliced Pile.—A pile composed of two or more sticks joined with scabs.

Spur Pile.—Same as "Batter Pile," *q.v.*

Square Hewed Pile.—A timber pile trimmed with an adze into an approximately square section.

Standing Pile.—A pile which stands without bracing.

Stay Pile.—A pile connected or anchored by land ties with the main piles in the face of pile work.

Steel Pile.—Piles made of rolled steel rods or shapes.

Test Pile.—A pile in place loaded with a known weight in order to test the bearing capacity of the soil.

Pile Band.—An iron band put around the head of a pile to keep it from splitting and brooming during driving.

Pile Bent.—See "Bent."

Pile Bridge.—See "Bridge."

Pile Cap.—See "Cap."

Pile-cluster.—Several piles driven close together forming a group or cluster.

Pile Disk.—The large, flat, circular casting which forms the footing of a disk pile.

Pile Driver.—A machine for sinking or driving piles.

Bull Wheel Pile Driver.—A pile driver having a bull wheel for winding up the lead line and raising the hammer. Pins are set in the periphery of the wheel convenient for the men to grasp and pull upon, thus rotating it.

Drop Hammer Pile Driver.—A driver in which a heavy hammer is repeatedly raised in a frame and dropped on to the pile.

Floating Pile Driver.—A pile driver mounted and operated on a scow or barge.

Gunpowder Pile Driver.—A device for exploding successive charges of gunpowder on top of the pile and, by the concussion, forcing the pile into the ground.

Hand Pile Driver.—A small pile driver operated by hand.

Horse Pile Driver.—A driver in which the hammer is raised by horsepower.

Monkey Pile Driver.—Same as "Hand Pile Driver," *q.v.*

Nipper Pile Driver.—A pile driver in which a nipper is used for engaging the hammer during lifting. It is tripped at the top of the leads.

Pendulum Pile Driver.—A driver in which the leads are arranged to swing like a pendulum so that a pile can be driven at an inclination to the vertical.

Track Pile Driver.—A driver mounted on a flat car in order to be readily moved along the track.

Pile Driver Hammer.—See "Hammer."

Pile Ferrule.—Same as "Pile Band," *q.v.*

Pile Follower.—Same as "Follower," *q.v.*

Pile Foundation.—See "Foundation."

Pile Hammer.—See "Hammer."

Pile Head.—See "Head."

Pile Line.—See "Line."

Pile Pier.—See "Pier."

Pile Planks.—See "Plank."

Pile Ring.—Same as "Pile Band," *q.v.*

Pile Ring Puller.—A device for pulling a pile ring from the head of a pile after it has been driven. Usually a cant hook is employed for this purpose.

Pile Shoe.—See "Shoe."

Pile Splice.—See "Splice."

Pile Trestle.—See "Trestle."

Pile Work.—See "Work."

Piling.—A general term for a number of piles taken together.

Sheet Piling.—A general term for a number of sheet piles taken collectively. See "Pile."

Pillar.—A post or column.

Pillaring.—The act of supplying with pillars. A system of pillars.

Pillow or Pillow Block.—See "Block."

Pillow Joint.—Same as "Ball and Socket Joint." See "Joint."

Pilot Nut.—See "Nut."

Pilot Punch.—See "Punch."

Pin.—A round bar of steel used for connecting members of a truss. Also any round bar which fills a hole. A pivot.

Centre Pin.—The pin on which the needle of a compass oscillates.

Chord Pin.—Any pin on, or very near, the centre line of a chord.

Pin.

Clevis Pin.—A pin used to connect a clevis with a plate.

Cotter Pin.—A split steel key or pin used to fasten large pins so that they cannot move endwise. Also used to denote the large pin holding the cotter.

Coupling Pin.—A pin that couples links in machinery, chains, etc.

Crank Pin.—A pin connecting the ends of a double crank or the projection from the end of a single crank.

Cross-head Pin.—A pin that fits in a cross-head and furnishes an attachment for the connecting rod..

Drift Pin.—A hand tool made of tempered steel with tapering ends and of a size that will permit its being pushed through a rivet hole. Used to draw together the component parts of a member or adjacent members.

End Pin.—A truss pin at the end of a span connecting the truss to the shoe.

Gudgeon Pin.—Same as "Gudgeon," *q.v.*

Guide Pin.—One of the pins which keep a hub and felloe central with the axis of the machine to which they pertain.

Hinge Pin.—A pin which fastens together the parts of a hinge or which connects members having a slight rotating movement about each other.

Linch Pin.—A pin, near the end of an axle, used to hold on a wheel.

Mast Pin.—A vertical pin at the top of the mast of a derrick.

Set Pin.—Same as "Dowel," *q.v.*

Shoe Pin.—The pin in a shoe which receives the load from a span or a column.

Truss Pin.—A pin used at the panel point of a truss to connect the several intersecting members.

Pin Bearing.—See "Bearing."

Pin-bolt.—A bridge pin having a head and a nut.

Pinch Bar.—See "Bar."

Pin-connected.—A term applied to the method of joining the members of a truss by pins instead of using riveted connections.

Pin-connected Truss.—See "Truss."

Pin Drill.—See "Drill."

Pine.—A species of the conifers, or evergreen trees.

Loblolly Pine.—A variety of pine tree of large size. It has a wider ringed, coarser, lighter, and softer wood with a larger area of sap wood than the long-leaf yellow pine. Its needle-like leaf is of short length.

Long-leaf Yellow Pine.—A variety of pine tree of large size, having a hard, dense, strong wood and a needle leaf of great length.

Norway Pine.—A variety of pine tree of large size. The wood is largely sap-wood and not durable. Grows in small scattering groves.

Short-leaf Yellow Pine.—A variety of pine tree resembling the loblolly pine and having a wood approaching that of the Norway pine. Its needle leaf is shorter than that of the loblolly or Norway pine.

White Pine.—A variety of pine tree of small size and soft wood. It has a short needle-like leaf.

Pin-end or **Pin-ended.**—The condition of having a pin connection at the end of a member.

Pin-end Column.—See "Column."

Pin Filler.—See "Filler."

Pinhole.—A hole in a member through which the pin passes and connects with other members.

Pinhole Cutter.—See "Cutter."

Pinion.—Any toothed gear of small size as compared with the gear which it engages.

Lantern Pinion.—A small lantern wheel. See "Wheel."

Pinion.

Lazy Pinion.—A pinion acting as an idle wheel.

Long Pinion.—A pinion having long teeth such that the gear meshing with it can move latterly without becoming disengaged.

Shrouded Pinion.—A pinion in which the sides of the rim extend up on the ends of the teeth, thereby bracing them and giving them extra strength.

Pinion Shaft.—See "Shaft."

Pin Joint.—See "Joint."

Pin Knot.—See "Knot."

Pin Maul.—See "Maul."

Pin Metal.—See "Metal."

Pinner.—In masonry construction, a small stone used to prop up a larger stone. The process involved (a most objectionable one) is termed "Pinning-up" or "Under-pinning." It causes the pressure on the block to be thrown on a few points instead of being equally distributed over it, and exposes the stone to cracking.

Pin Nut.—See "Nut."

Pinny.—An English term for a metal which contains enclosed particles of metal harder than the rest.

Pin Pilot.—Same as "Pilot Nut." See "Nut."

Pin Plate.—See "Plate."

Pipe (in metal).—A defect in an ingot due to the metal cooling from the outside inward, and the resulting contraction leaving a cavity near the center at the top.

Pipe.—A tube, a conduit, a hollow metallic cylinder.

Blast Pipe.—The exhaust pipe of a steam engine.

Blow Pipe.—A pipe through which material is forced by air from a caisson. A small tube through which air is forced so as to produce a high temperature.

Cast-iron Pipe.—Pipe made of cast iron.

Drip Pipe.—A small pipe used to convey away the water of condensation from a steam pipe.

Jet Pipe.—A pipe used in jetting, having a nozzle at the lower end and the water supply hose at the upper.

Joint Pipe.—A short section of gas or steam pipe.

Gas Pipe.—Small wrought iron pipe.

Lead Pipe.—Pipe made by squeezing lead through a die.

Loricated Pipe.—A pipe, having an inside coating of bitumen, used as a conduit for electric wires.

Spiral-riveted Pipe.—A pipe made of long, narrow, steel plates twisted into a spiral form and riveted together.

Suction Pipe.—The pipe running from a pump to the water supply.

Weeping Pipe.—A pipe embedded in the masonry to carry off quickly the water from the top or back of a pier or abutment.

Wrought-iron Pipe.—Pipe made from rolled iron plates and welded at the joint. Small sizes are butt-welded, while larger sizes are lap-welded.

Pipe Clamp.—See "Clamp."

Pipe Coupling.—See "Coupling."

Pipe Cutter.—See "Cutter."

Pipe Die.—See "Die."

Pipe Joint.—See "Joint."

Pipe Line.—See "Line."

Pipe Rail.—See "Rail."

Pipe Tongs.—See "Tongs."

Pipe Union.—See "Union."

Pipe Vise.—See "Vise."

Pipe Wrench.—See "Wrench."

Piping.—A general term used to denote a group or system of pipes taken collectively. A defect in rolled steel due to cavities that were formed as the ingot cooled. See "Pipe."

Piston.—A movable disk-like piece fitted to fill the cross-section of a pipe or cylinder and capable of a backward and forward motion.

Air Piston.—The piston that works in the air cylinder of an air compressor.

Double-acting Piston.—A piston that is subjected to fluid pressure on each side alternately.

Single-acting Piston.—A piston which is subjected to periodic pressure on one side only.

Piston-head.—Same as "Piston," *q.v.*

Piston Rod.—See "Rod."

Piston Valve.—See "Valve."

Pit.—The effect of steam, water, or gas on metal causing small holes to appear on the surface. A hole in the ground.

Foundation Pit.—An excavation in which a foundation is placed.

Lock Pit.—A pit in which the locking machinery is installed.

Working Pit.—The excavation made for a foundation.

Pitch.—The distance measured along the pitch line from center to center of teeth on a cogwheel. The slope of a roof. The distance from center to center of rivets. The distance between the adjacent threads of a screw. The degree of descent of a declivity. A thick, tenacious, black or dark-brown substance obtained by boiling down tar. The resinous sap that exudes from pines. Bitumen or asphaltum, especially when unrefined. To smear, cover, or treat with pitch.

Chord Pitch.—The distance between centres of teeth, measured on the chord of the pitch circle of a gear.

Circular Pitch.—The distance between centres of teeth, measured on the pitch circle of a gear. Also called the pitch of the tooth.

Diametral Pitch.—In English practice, the ratio of the diameter of the pitch line to the number of teeth which is equivalent to the ratio of the circular pitch to π. In American practice, the ratio of the number of teeth to the diameter of the pitch circle in inches, which is equivalent to the ratio of π to the circular pitch.

Pitch Circle.—That circle of a gear, passing through the teeth, having a diameter which measures the velocity ratio of the gear in respect to another which engages it.

Pitched Dressing, or **Pitched-face Dressing.**—See "Dressing."

Pitching Chisel.—See "Chisel."

Pitching Tool.—A hand tool used by masons for cutting the arris on a stone.

Pitch Line.—See "Line."

Pitch of Rivet.—See "Rivet."

Pitch Streak.—A well-defined accumulation of pitch at one point in a piece of timber.

Pitch Wheel.—See "Wheel."

Pitman.—A rod which connects a rotating with a reciprocating part in an engine or other machine.

Pit Planer.—See "Planer."

Pit Saw.—See "Saw."

Pivot.—A pin or shaft on which any object turns.

Pivoted.—Arranged to work on a pivot.

Pivot Gearing.—See "Gearing."

Pivot Joint.—See "Joint."

Pivot Pier.—See "Pier."

Pivot Span.—A span in a bridge that revolves; called also "draw-span" and "swing-span."

Plain Dressing.—See "Dressing."

Plain Hammer.—Same as an "Engineer's Hammer." See "Hammer."

Plain Rod.—See "Rod."

Plan.—The general layout of a structure; the horizontal projection of an object or structure.

Plane.—A surface generated by a straight line moving parallel to its original position.

Datum Plane.—A plane of reference for a system of levels which, generally, is taken as zero elevation.

Diametral Plane.—A plane passing through the diameter of a circle, or one containing the longitudinal axis of a cylinder.

Inclined Plane.—A plane which makes an angle with the horizontal.

Jack Plane.—A carpenter's tool for smoothing boards.

Plane Curve.—See "Curve."

Planed Finish.—See "Finish."

Planed Joint.—See "Joint."

Plane of Rupture.—See "Rupture."

Plane of Symmetry.—See "Symmetry."

Planer.—A machine tool for planing metal.

Pit Planer.—A type of planer located in a pit so that large work may be placed thereon.

Stone Planer.—A machine for smoothing the surfaces of flat stones.

Plane Table.—A surveyor's instrument consisting of a drawing board mounted on a tripod, and having on its upper surface a movable straight-edge arranged with sight vanes or a telescope.

Planimeter.—An instrument for measuring a plane area by carrying a tracer around its periphery and noting the change of reading on the index of the rolling wheel.

Polar Planimeter.—A planimeter having a hinged arm, one end of which is pivoted while the other end carries the tracing point.

Rolling Planimeter.—A planimeter in which the tracer arm is pivoted to a short bar mounted on rollers.

Planish.—To polish metals by rubbing with a hard, smooth tool.

Plank.—A piece of lumber thicker than a board; usually measures from two to four inches in thickness and from six inches upward in width.

Felloe Plank, or Felly Plank.—A guard rail on a roadway, so placed as to catch the felloe of a wheel and thus prevent the vehicle from striking the truss. In wide bridges, a felloe plank is often placed midway between the trusses, to prevent vehicles passing from one side to the other.

Floor Plank.—A plank used in the flooring of a highway bridge.

Gang Plank.—A short, temporary plank used to bridge the distance from a barge or other vessel to a wharf.

Hub Plank.—See "Hub."

Moulding Planks.—Planks on which ornamental mouldings are placed while in a soft condition.

Pile Planks.—Planks driven like piles.

Plank Pile.—See "Pile."

Plant.—The fixtures, machinery, tools, apparatus, etc. used to carry on any manufacturing or erecting business.

Plate.—A flat piece of metal or wood.

Anchor Plate.—A square or rectangular plate, or washer, at the bottom of an anchor bolt.

Base Plate.—The foundation plate of metal on which a heavy piece of machinery or the end of a bridge rests. This plate is usually set on masonry or concrete.

Batten Plate.—A stayed plate at the ends of a compression member. Sometimes termed tie plate or stay plate.

Beam-hanger Plate.—The plate beneath the ends of a floor beam for the beam-hanger nuts to press against.

Bearing Plate.—A plate which receives the bearing from a pin or a plate that bears on another plate.

Plate.

Bed Plate.—A plate set in the top of the masonry to carry the load from the span.

Boiler Plate.—Iron or steel rolled into flat plates from one-quarter to one-half inch thick, used in making tanks, boilers, vessels, etc. Sometimes called "boiler iron."

Buckle Plates.—Flat, steel plates which are dished at regular intervals. Used for floor plates.

Cap Plate.—The top plate on a steel column or post. It generally supports a load.

Checkered Plate.—A cast steel or iron plate having square, flat projections suggestive of a checkerboard. Its function is to give a foothold for horses.

Compound Web Plate.—See "Web Plate."

Connecting Plate.—A plate used to connect two or more members of a truss.

Corrugated Plate.—A steel plate bent into a series of parallel furrows and ridges.

Cover Plate.—A plate fastened on the flanges of a girder to give additional cross-section thereto; a top or bottom plate of a chord member.

Diaphragm Plate.—A stiffening plate used in the interior of a column to give it additional strength and rigidity.

Draw Plate.—A plate having tapered holes through which wires are drawn.

Extension Plate.—See "Jaw Plate."

Filler Plate.—A plate used to fill open spaces under members or parts thereof

Fish Plate.—Same as "Splice Bar." See "Bar."

Flange Plate.—Same as "Cover Plate," *q.v.*

Flitch Plate.—A plate in a compound wood and steel beam.

Gusset Plate.—A large connecting plate used at panel points to join the chord and the web members.

Hanger Plate.—A gusset plate connecting the hip-vertical to either the top or the bottom chord.

Hinged Plate.—A plate containing a pinhole for hinging the end of a member.

Hitch Plate.—A plate having a hole or a ring attached for tying lines thereto.

Jaw Plate.—The unsupported portion of the end of a compression member remaining after the outstanding legs of flange angles have been cut away, and its pin plates, which extend below the transverse diaphragm to allow the packing of other members on the same pin.

Masonry Plate.—A plate used under a bridge-shoe for the purpose of distributing the load on the masonry.

Name Plate.—A plate attached to a bridge showing the names of the designer, fabricator, and erector. Sometimes other names are added.

Pin Plate.—A plate riveted to the outside of the end of a member to give additional strength and greater bearing on the pin.

Reinforcing Plate.—An extra plate used to reinforce or strengthen a member.

Roller Plate.—A bed plate on which the rollers of the expansion end of a truss rest.

Scab Plate.—Same as "Scab," *q.v.*

Sheared Plate.—A plate sheared from another larger plate. Any plate the edges of which are sheared.

Shimming Plate.—A plate used as a shim for increasing the elevation of a bearing.

Shoe Plate.—The bottom plate of a shoe resting on the masonry.

Skimming Plate.—A cast iron plate used to separate from the molten metal the small amount of a slag which comes out of the furnace therewith.

Sole Plate.—A plate riveted to the bottom flange of a plate girder to bear on the masonry plate.

Splice Plate.—A plate used in splicing or joining two parts of a member.

Stay Plate.—Same as "Batten Plate," *q.v.*

Tie Plate.—Same as "Batten Plate," *q.v.* A plate used between a rail and a tie.

Tongue Plate.—A plate riveted on to the end of a member and projecting beyond it, in order to make a connection with another member.

Plate.

Trough Plate.—A rolled steel shape having a cross-section similar to that of a trough with sloping sides. Used for floor plates.

Universal Mill Plate.—A plate rolled on a universal mill, giving thereto smooth, square edges.

Wall Plate.—A steel plate laid on a masonry or a concrete wall to carry the end of a beam and to distribute its load.

Web Plate.—The plate forming the web of a girder.

Vernier Plate.—The revolving plate on a transit to which are attached the verniers.

Plate Gauge.—See "Gauge."

Plate Girder.—See "Girder."

Plate Washer.—See "Washer."

Play.—A looseness in a joint or in parts of a machine or structure permitting some freedom of motion.

Plenum Process.—The pneumatic process for sinking piers. See "Pneumatic Process."

Pliability.—The capacity of a body to change its form, temporarily, under different stresses.

Pliers.—A hand tool for manipulating and cutting wires.

Plinth.—The square block at the base of a column or pedestal.

Plug.—A small block of any material used to stop a hole. Also a wedge-shaped piece of steel used to drive between the feathers in the "Plug and Feather" method of splitting or quarrying stone.

Plug-and-feather Method.—A method of breaking a stone slab by drilling holes, a few inches apart, to a convenient depth less than the thickness of the stone; then inserting steel feathers in each hole and driving a long slim wedge, or plug, between them. This causes an expansion and a cracking along the line of holes.

Plug Cock.—See "Cock."

Plugged.—Stopped up with a plug.

Plugged Rivet.—Same as "Calked Rivet." See "Rivet."

Plumb.—Vertical.

Plumbago.—Same as "Graphite," *q.v.*

Plumb-bob.—A conical piece of metal attached at its large end to a cord. Used to place an object in a vertical position or directly over some desired point.

Plumb Line.—See "Line."

Plumb Pile.—See "Pile."

Plumb Post.—See "Post."

Plummer Block.—Same as a "Pillow Block." See "Block."

Plummet.—A ball of metal attached to the end of a line used in sounding the depth of water.

Plunger.—The piston in a pump.

Ply.—A term used to designate the number of layers in a fabric, as a three-ply hose or a four-ply belt.

Pneumatic.—Pertaining to air, processes using air, or machines worked by compressed air.

Pneumatic Caisson.—See "Caisson."

Pneumatic Car.—See "Car."

Pneumatic-clippers.—Shears or clippers operated by compressed air.

Pneumatic Cutter.—See "Cutter."

Pneumatic-cylinder.—The cylinder of a pier sunk by the pneumatic process. The cylinder in an air-compressor in which the air is compressed.

Pneumatic Drill.—See "Drill."

Pneumatic Elevator.—See "Elevator."

Pneumatic Excavator.—See "Excavator."

Pneumatic Hammer.—See "Hammer."

Pneumatic Hoist.—Same as "Air Hoist." See "Hoist."

Pneumatic Pier.—See "Pier."

Pneumatic Pile.—See "Pile."

Pneumatic Process.—The process of sinking caissons by pumping air into the working chamber, in order to exclude the water, and thereby affording a dry space in which excavation may be carried on.

Pneumatic Riveter.—Same as "Air Riveter." See "Riveter."

Pneumatic Riveting Gun.—See "Gun."

Pocket.—A recess. A hole in rolled metal, as a cinder pocket.

Cinder Pocket.—A pocket made in rolled steel by rolling cinders into the metal. These may either remain or drop out of the rolled product, leaving holes or pockets.

Expansion Pocket.—A bracket or pocket carrying a sliding end of a girder.

Pœtsch Freezing Process.—A method of freezing quicksand, soft mud, or silt by driving tubes down into it and circulating a freezing mixture through them until the surrounding material is converted into a frozen mass like a wall. Excavation can then be carried on inside of the wall.

Pœtsch-Sooysmith Process.—Same as the "Pœtsch Freezing Process," *q.v.* This term is used to denote the American right, held by Mr. Charles Sooysmith, to use the process.

Point (gear teeth).—See "Tooth."

Point (stone dressing).—A short steel bar with one tapering end sharpened to a point, used by masons for dressing stone.

Pointed Dressing.—See "Dressing."

Point of Curve.—On railroad work, the point at which a tangent ends and a curve begins, called P. C.

Point of Intersection.—The point where two tangents cross. Used in railroad work and called P. I.

Point of Tangent.—In railroad work, the point where a curve ends and a tangent commences, called P. T.

Point Switch.—See "Switch."

Poisson's Ratio.—The ratio of the lateral deformation to the longitudinal deformation under longitudinal external forces.

Polar.—Relating to a pole or axis.

Polar Axis.—See "Axis."

Polar Coordinates.—See "Coordinates."

Polar Distance.—Same as "Pole Distance," *q.v.*

Polar-equation.—An equation connecting polar coordinates.

Polar Moment of Inertia.—See "Inertia."

Polar Planimeter.—See "Planimeter."

Pole.—Any long, round, slender piece of wood. Either of the extremities of the axis of a sphere. A point about which an object rotates. A point from which lines radiate.

Leveling Pole.—Same as "Leveling Rod." See "Rod."

Range Pole.—A slender, painted pole having red and white bands alternating to give distinctness. Used by surveyors in sighting and running lines.

Pole Axe.—See "Axe."

Pole-distance.—The perpendicular distance, in a force diagram, from the pole to the load line.

Pole-plate.—A longitudinal timber resting on the ends of tie-beams of roofs; used for supporting the feet of the common or jack rafters.

Pole Tie.—See "Tie."

Poling.—The stirring of molten metal, either in a furnace or in a ladle, with a pole of green wood; the heat distilling off the volatile products which stir up the metal and; together with the charcoal formed, help to reduce any oxides present. Also propelling a barge or vessel by long poles.

Polished Dressing. -See "Dressing."

Polygon.—An enclosed figure having many sides and angles.

Equilibrium Polygon.—A term used in graphic statics to designate the polygon drawn through a system of non-concurrent forces in order to determine the position of the resultant thereof. The sides of the polygon are made parallel to the rays of an accompanying force polygon, *q.v.*

Force Polygon.—A polygon used in graphic statics to determine the magnitude and direction of the resultant of a system of forces. The sides of the polygon are made parallel to and equal in length to the forces. The closing line represents the magnitude and direction of the resultant.

Funicular Polygon, or String Polygon.—Same as "Equilibrium Polygon," *q.v.*

Polygonal Top Chord.—See "Chord."

Pontoon.—A boat or light float. A metal cylinder closed at both ends for floating. A floating bridge.

Pontoon Bridge.—See "Bridge."

Pony Truss.—See "Truss."

Porosity.—The condition of perviousness.

Port.—The narrow slot in the ends of a cylinder for the passage of steam. In a vessel, the left-hand side looking forward—termed also "larboard." A harbor or shelter for vessels.

Portal.—The space between the batter braces at one end of a bridge. Sometimes the term is applied to the portal bracing.

Skew Portal.—A portal on a skew span.

Portal Bracing. -See "Bracing."

Portal Rod.—See "Rod."

Portal Strut.—See "Strut."

Portland Cement.—See "Cement."

Portland Cement Concrete.—See "Concrete."

Portland Cement Grout.—See "Grout."

Positive Moment.—See "Moment."

Positive Print.—See "Print."

Positive Reaction.—See "Reaction."

Positive Rotation.—See "Rotation."

Positive Shear.—See "Shear."

Post.—A vertical, or nearly vertical, compression member.

Batter Post.—Same as "Batter Brace." See "Brace."

Beam-trussing Posts.—The short, perpendicular posts used in trussing beams.

Centre Post.—An intermediate post on the longitudinal centre line of a timber bent.

Collision Post.—An auxiliary post placed near the portal of a bridge to take up the shock of a derailed car or engine and prevent it from injuring the trusses.

End Post.—The post at the end of a truss.

Fixed Post.—A post having fixed ends.

Handrail Post.—A post supporting the handrail and its attachments. The vertical member of a handrailing.

Hinged Post.—A post having one or both ends connected by pins to other parts of the structure.

Inclined End Post.—An inclined compression member at the end of the truss. Also called "Batter Post" and "Batter Brace."

Intermediate Post.—A post between the two outside posts in a timber bent.

Post.

Joggle Post.—A post built of two or more pieces of timber held together with dowels or joggles. A post having shoulders to receive the feet of struts; a king post.

King Post.—The middle post standing at the apex of a King Post Truss. See "Truss." Also called "Joggle Post," *q.v.*

Newel Post.—The principal post at the angles or at the foot of a stairway.

Plumb Post.—A vertical post, usually applied to timber construction.

Queen Post.—The vertical post in a "Queen Post Truss." See "Truss."

Snubbing Post.—A post used for snubbing or attaching loosely a line to check the motion of a boat.

Sub Post.—A secondary post used in a subdivided panel.

Tower Post.—A member of a tower which carries load directly to the pedestal. A tower column.

Post Extension.—Same as "Jaw Plate," *q.v.*

Post-hole Auger.—See "Auger."

Post-Oak.—A variety of white oak.

Post Reamer.—Same as "Post-hole Auger," *q.v.*

Post Truss.—See "Truss."

Potential Energy.—See "Energy."

Pot Metal.—See "Metal."

Pounce.—Powdered talc or chalk used for rubbing on tracing cloth to remove the slightly greasy surface so that the ink will adhere better.

Pound-foot.—A unit of moment, equal to that produced by a force of one pound acting with a lever arm of one foot.

Powder.—Same as "Gun Powder," *q.v.* An explosive used for blasting. Any very finely pulverized substance. To reduce to powder. To pulverize. To sprinkle with powder.

Power.—The rate of doing work. Often loosely used for force, strength, or resistance.

Horsepower.—A unit of power. See "Horsepower." Also a machine by which the power of a horse can be made available for doing useful work.

Water-power.—Power developed from moving water; also applied to any plant used for generating power from moving water.

Power Capstan.—See "Capstan."

Power Crane.—Same as "Column Crane," *q.v.*

Power Hammer.—See "Hammer."

Power House.—The building containing the machines and equipment used in generating power.

Pozzuolana Cement.—See "Cement."

Prairie-type Locomotive.—See "Locomotive."

Pratt Truss.—See "Truss."

Pre-cast Pile or **Pre-moulded Pile.**—See "Pile."

Precipitation.—A general term for the several kinds of moisture from the atmosphere deposited on the earth's surface, such as dew, mist, rain, frost, snow, sleet, hail, etc. The process by which a substance in solution, after another substance has been added, reacts upon the latter, forming a new insoluble compound called precipitate.

Precise Level.—See "Level."

Present Worth.—The present worth of a sum of money due a number of years hence is that principal which at compound interest will produce the desired amount at the end of the given time. The present worth of a sinking fund is equal to the present worth of the amount of the fund, and is the sum of the present worths of the deposits.

Press.—A machine for exerting pressure upon an object.

Buckle-plate Press.—A machine for pressing sheet steel into buckle-plates.

Bull Press.—Same as "Gag Press," *q.v.*

Press.

Drill Press.—A machine tool for drilling holes, having one or more spindles carrying drill points that are moved forward by an automatic feed.

Gag Press, or **Gog Press.**—A press consisting of two fixed horns and a ram, used for straightening structural shapes. Also called "Bull Press."

Hydraulic Press.—A press consisting of a water cylinder and movable plunger mounted in a frame. A small pump forces water into the cylinder and causes the plunger to move slowly, but with great pressure against the object held in the frame.

Steel Press.—A machine used in the manufacture of steel for pressing or squeezing out the slag. The action thereof may be continuous or intermittent.

Pressed Brick.—See "Brick."

Pressed Threads.—See "Threads."

Pressure.—The effect of pressing; the result of thrust.

Air Pressure.—The pressure exerted by the air due to its weight or to its being compressed and confined in a reservoir.

Axis of Pressure.—A line passing through the centroids of pressure of different successive sections of a body.

Bearing Pressure.—The pressure on a bearing.

Centre of Pressure.—The point at which the resultant of the pressures on a surface acts.

Earth Pressure.—The lateral pressure exerted by a bank of earth when supported by a retaining wall or an abutment.

Tooth Pressure.—The pressure exerted by a tooth of a gear on the opposing gear.

Water Pressure.—The pressure exerted by a column of water when confined.

Wind Pressure.—The pressure on a surface produced by the wind blowing against it.

Pressure Gauge.—See "Gauge."

Pricker.—A needle point mounted in a handle, used by draughtsmen to transfer the position of a point on one plan to another by superposing one on the other and pricking through.

Prick Punch.—See "Punch."

Primary Member.—See "Member."

Primary Stress.—See "Stress."

Primary Truss.—See "Truss."

Prime.—To pour water down a pump in order to start the suction.

Primer.—The first coat of paint on a structure; an exploder for blasting powder.

Priming Coat.—The first coat of paint on a structure. Sometimes called "Primer," *q.v.*

Principal.—A sum of money upon which interest is paid or computed.

Principle of Least Work.—See "Least-work."

Print.—An impression; a copy.

Blue-print.—A copy made on blue-print paper from a tracing. See "Paper."

Negative Print.—An intermediate print from which the final or positive print is made.

Positive Print.—A blue line print on white background made by a direct process without a negative.

Van Dyke Print.—A print made on Van Dyke brown-print paper.

Printing Frame.—See "Frame."

Printing Machine.—An apparatus for making blue-prints by either natural or artificial light.

Prismoid.—A solid having two parallel plane bases with sides generated by straight lines.

Prismoidal Formula.—A formula for finding the exact volume of a prismoid.

Let A_1 = area of one base,

A_2 = area of other base,

M = area of middle section parallel to bases,

Let l = distance between bases,
V = volume,

then $V = \frac{l}{6}(A_1 + A_2 + 4M)$

Prison Dressing.—See "Dressing."

Profile.—The outline of a vertical section through a country or line of work, showing actual or projected elevations and hollows, generally with the vertical scale much greater than the horizontal.

Profile Book.—A surveyor's note book. A case in which a continuous strip of profile paper is carried.

Profile Paper.—See "Paper."

Progression.—A series of numbers bearing a definite sequential relation to each other.

Arithmetical Progression.—A progression in which any term, other than the first, is derived from the preceding term by adding a fixed quantity.

Geometrical Progression.—A progression in which any term, other than the first, is derived from the preceding term by multiplying the latter by a fixed quantity.

Projection.—The act, or its result, of constructing rays or lines through every point of a figure, according to some system or law, and extending or projecting them to some plane upon which the figure or object is to be represented.

Isometric Projection.—A mode of geometrical drawing in which three planes are projected at equal angles upon a single plane, and all the measurements are upon the same scale; used at times to show machinery, buildings, etc.

Orthographic Projection.—That system of projection in which the rays are parallel. This is the system which is most largely used in engineering work.

Prony Friction Brake.—See "Brake."

Proof Load.—See "Load."

Proof Strength.—See "Strength."

Prop.—A temporary support or extraneous brace.

Pry.—A lever. To raise with a lever.

Puddle.—To compact and work into place, as to puddle concrete. To convert cast iron into wrought iron by melting and stirring in a reverberatory furnace. A mixture of sticky clay moistened with water, used to stop leaks in cofferdams, etc. To place such a mixture.

Puddle Ball.—A lump of red-hot, plastic iron taken from the puddling furnace for hammering or rolling.

Puddle Bar.—Same as "Muck Bar." See "Bar."

Puddle Cinder.—See "Cinder."

Puddle Dyke.—See "Dyke."

Puddler.—A workman who is employed in the process of converting pig iron into wrought iron. The attendant at a puddling furnace.

Puddle Rolls.—See "Rolls."

Puddler's Candle.—One of the jets of flame which spring from molten iron while the carbon is being removed in a puddling furnace.

Puddle Steel.—See "Steel."

Puddle-train.—A set of rolls for rolling puddle balls into muck bar.

Puddle Wall.—See "Wall."

Puddling.—The act of making a puddle. See "Puddle."

Dry Puddling.—The old process of puddling iron in which very little, if any of the phosphorus was removed, while the sand lining of the furnace combined with the iron which was oxidized, thus causing a heavy loss.

Wet Puddling.—The present process of puddling, in which the furnace is first charged with fluxing cinder or "hammer slag" (oxide of iron) and then with gray iron. Afterward the charge is heated so that the iron and the flux form a pasty mass, which is then stirred with puddling bars.

Puddling Furnace.—See "Furnace."

Pug-mill.—A machine for grinding and tempering clay.

Pull-back Draw Bridge.—See "Bridge."

Pulley.—A wheel over which a belt, chain, or rope passes; used to transmit motion or to deflect such belt, chain, or rope from one course to another. The face may be flat, crowned, conical, or grooved. Also applied to a combination of sheaves, or grooved pulleys, and the shell or framework containing them. Also called "Pulley Block." See "Block."

Band Pulley.—A flat or slightly crowned pulley operated by a band.

Chain Pulley.—Same as "Chain Wheel," *q.v.*

Clip Pulley.—A wheel which has on its face a series of grips or clips for holding the band or wire rope that passes over it.

Compound Pulley.—Properly speaking, this term refers to a system of pulley-blocks and ropes usually called "Tackle," *q.v.*

Cone Pulley.—Same as "Stepped Pulley," *q.v.*

Conical Pulley.—A pulley having a conical face.

Crowning Pulley.—A pulley in which the face has a slight convexity in order to hold the belt on better.

Dead Pulley.—Same as "Loose Pulley," *q.v.*

Differential Pulley.—A system of pulleys in which an endless chain passes over two upper grooved pulleys, of different diameters, and one lower pulley to which the weight to be lifted is attached. The motion of the chain is such that as it winds upon the larger pulley, it unwinds from the smaller and the weight to be lifted moves through a space equal to half the difference between the amount of chain wound up and that unwound.

Double-speed Pulley.—A combination of two loose pulleys and toothed gearing with one fast-driven pulley, whereby two different speeds of rotation may be obtained with pulleys of the same diameter by shifting the band from the fast pulley to one of the loose pulleys.

Driven Pulley.—The pulley which receives the motion from the belt.

Driving Pulley.—The pulley transmitting motion to the belt.

Fast Pulley.—A pulley which is fastened to its shaft.

Flat-rope Pulley.—A pulley having a flat face, but with flanges at the edges, over which passes a flat rope.

Frame Pulley.—A type of pulley-block having an iron frame in which the sheaves or grooved pulleys turn.

Friction Pulley.—A pulley which transmits its motion to another by friction of the rolling-surfaces instead of by teeth.

Guide Pulley.—A pulley employed to alter the course of a belt.

Idle Pulley.—Same as "Loose Pulley," *q.v.*

Jockey Pulley.—A small wheel running against the rim of a grooved wheel to keep the rope or chain in its groove.

Loose Pulley.—A pulley which turns loosely on its shaft.

Parting Pulley.—Same as "Split Pulley," *q.v.*

Sliding Pulley.—A pulley with a clutch mechanism.

Split Pulley.—A pulley made of two parts, held together by bolts, and so arranged that it can be removed from its shaft without disturbing the latter.

Stepped Pulley.—A pulley having a stepped face or parts with different diameters, thus permitting of a shifting of the belt and the transmission of different speeds.

Pulley Block.—See "Block."

Pulley-check.—An automatic device to prevent the rope from running backward through the pulley block.

Pulley Clutch.—See "Clutch."

Pulley Sheave.—See "Sheave."

Pulsometer, or Pulsometer Pump.—A pump in which the condensation of steam in a chamber causes a partial vacuum therein, inducing the water to rise so as to be expelled therefrom by an incoming fresh supply of steam.

Pulverize.—To reduce to a powder.

Pump.—A machine for moving liquids or gases by setting up a flow of same.

Air Pump.—A pump for condensing and forcing air through an aperture or pipe.

Bucket Pump.—A pump for raising liquids by means of buckets attached to a belt or chain and passing over an overhead shaft or a pulley or sprocket wheel.

Centrifugal Pump.—A rotary pump in which a revolving fan creates a partial vacuum in its chamber, causing the water to rise until it comes in contact with the swiftly moving vanes by which it is expelled through the discharge pipe.

Chain Pump.—A pump employing an endless chain provided at intervals with buckets or with flat valves or disks working in a tube, used for raising water short distances. It is an uneconomic device.

Donkey Pump.—A feed pump for boilers.

Eads' Pump.—A pump employing a water jet to entrain air and thereby suck up mud and wet sand into a chamber where it is caught by the jet and carried out through a discharge pipe.

Emerson's Foundation Pump.—A pump specially adapted for pumping out cofferdams or cribs.

Feed Water Pump.—Same as "Donkey Pump," *q.v.*

Hand Pump.—A pump worked by man power.

Horizontal Pump.—A pump with its cylinders in a horizontal position.

Jack-head Pump.—A pump having its delivery pipe attached to the pump barrel by a goose-neck connection.

Jet Pump.—Any pump in which the fluid is impelled through the discharge pipe by the action of a jet of the same or another fluid.

Jigger Pump.—A portable, hand-lever pump, usually provided with an attachment for an air chamber and a nozzle to which a hose may be attached.

Lift Pump.—A pump having a cylinder with a suction valve at its lower end which is connected by a suction pipe to the water supply. The movable piston has an upward opening valve so that the water may pass through it on the downward stroke and lift by it when closed on the upper stroke.

Locomotive Pump.—The feed pump which supplies water to a locomotive boiler.

Mud Pump.—A pump used for pumping mud out of an excavation, usually a centrifugal pump, although sometimes a jet pump, such as the Eads' pump is employed.

Pulsometer Pump.—Same as "Pulsometer," *q.v.*

Rotary Pump.—A pump that lifts water by the rotary motion of its parts.

Sand Pump.—A pump for raising sand, such as the Eads' pump.

Suction Pump.—A pump that raises water by creating a partial vacuum or suction.

Punch.—A machine for forcing or shearing holes in metal. To make a hole with a punch.

Backing-out Punch or B. & O. Punch.—A hand tool used by erectors for backing out of the rivet-hole that portion of the rivet remaining after cutting off the head. Also called "B. and O. Punch."

Centre Punch.—A marking punch that makes a small indentation in steel so as to locate the centre for a rivet-hole.

Gang Punch.—A machine that punches two or more holes at one operation.

Multiple Punch.—Same as "Gang Punch," *q.v.*

Pilot Punch.—A machine punch in which the cutting tool is provided with a small central plug which fits into a hole in the material and acts as a guide for punching the larger hole.

Prick Punch.—A hand tool for marking metal. A centre punch.

Ratchet Punch.—A punching machine that is operated by means of a ratchet wheel.

Punch.

Single Punch.—A punching machine that makes one hole at a time.

Spacing Punch.—A punch with an arm extending horizontally and having on the end of this arm a small tool, called a spotter, which engages a template working on a frame, to which is attached the sheet to be punched. When the frame is moved so that the spotter enters the hole in the template, the punch acts.

Square Punch.—A machine for punching square holes.

Sub-punch.—To punch a hole smaller than the rivet to be used, so that the injured metal may be removed by reaming out to size.

Template Punch.—Same as "Spacing Punch," *q.v.*

Punching Machine.—Same as "Punch," *q.v.*

Punish.—To subject material to very severe or abusive treatment.

Purchase.—A firm or advantageous hold used in prying a heavy object with a crow-bar. A pivot, a fulcrum.

Purchase Blocks.—See "Block."

Pure.—Unadulterated.

Pure Stress.—See "Stress."

Purlin.—A piece of timber laid horizontally upon the principal rafters of a roof to support the common rafters on which the covering is laid.

Push.—To strike or force with a thrusting motion.

Pusher.—A sub-foreman, in charge of one gang, who sees that the men do the work assigned to them as rapidly as possible.

Put-log.—A horizontal piece supporting the floor of a scaffold, one end being inserted in a hole left in the masonry for that purpose.

Putty.—A paste composed of soft carbonate of lime and linseed oil, used by glaziers for holding window-glass in a sash.

Putty Joint.—See "Joint."

Putty Lime.—See "Lime."

Q

Quadrangular Truss.—See "Truss."

Quadratic Equation.—An equation of the second degree, or one in which the highest power of the unknown quantity is the second.

Quadruple Block.—See "Block."

Quantities.—The amounts of materials to be handled, expressed in the customary units.

Quarry.—An excavation from which rock is obtained.

Quarry-faced Dressing.—See "Dressing."

Quarry Moisture.—The moisture held in the pores of recently quarried rocks.

Quarry Sap or **Quarry Water.**—See "Quarry Moisture."

Quartered Tie.—See "Tie."

Quartz.—A hard, translucent mineral occurring in either crystalline or massive form. One of the constituents of granite, sandstone, and sand. Chemically, it is the oxide of silicon ($Si\,O_2$).

Quay.—A wharf, *q.v.*

Queen Post.—See "Post."

Queen Post Truss.—See "Truss."

Quenching.—The hardening of steel by dipping in a liquid, such as water or oil. Sometimes molten lead is used for this purpose.

Quick Lime.—See "Lime."

Quick Sand.—A very fine, silt-like sand saturated with water so that it has no stability.

Quick-setting Cement.—See "Cement."

Quiescent Load.—A load that is stationary.

Quirk.—An acute angle or recess. A deep indentation. The incision under the abacus.

Quoin.—An exterior solid angle in masonry. A wedge-like piece of stone or metal. To wedge or raise up.

R

Rabbet.—A half groove along the edge of a board. To cut such a groove.

Rabbeting Machine.—A machine for cutting rabbets in boards.

Rabbet Joint.—See "Joint."

Rabble.—A bar with one end bent at right angles like a poker, used in puddling furnaces.

Rabbling.—Same as "Puddling," *q.v.*

Rack.—A straight iron bar having teeth for engaging those of a gear or a worm. Used to convert rotary motion into rectilinear, or *vice versa.*

Roll Rack.—A rack on which a pinion works.

Worm Rack.—A rack having oblique teeth on which a worm meshes.

Rack and Pinion.—A combination of a rack and a pinion working together.

Rack and Pinion Jack.—See "Jack."

Rack-circle.—A rack bent into the form of a circle.

Racked-back.—Built in steps or offsets.

Racking.—Shaking so that the connecting rivets are loosened and the structure thus permanently injured.

Rack-rail.—Same as "Rack," *q.v.*

Rack Tooth.—See "Tooth."

Radial-arm.—A crank or rod revolving about a centre at one end, such as the crank of a windlass.

Radial Drill.—See "Drill."

Radial Rod.—See "Rod."

Radial Strut.—See "Strut."

Radian.—The unit of circular measure equal to an angle which has a subtending arc of the same length as the radius.

Radius of Curvature.—See "Curvature."

Radius of Gyration.—See "Gyration."

Radius Tool.—See "Tool."

Raft Dog.—See "Dog."

Rafter.—One of the timbers or joists in a roof to which the boards are fastened.

Jack Rafter.—One of the short rafters used in a hip-roof.

Rag-Bolt.—Same as "Bar Bolt," *q.v.*

Rag Wheel.—See "Wheel."

Rail.—A specially shaped bar adapted to a particular purpose. It may be of wood, stone, concrete, or metal. Generally used for supporting vertical loads.

Base of Rail.—The bottom of any rail laid in final position. It generally determines the elevation from which the heights of the various parts of the structure are measured.

Flange Rail.—A rail having on one side an elevated edge or flange to keep the wheels from running off.

Girder Rail.—A deep, heavy rail used for street cars in cities. Its cross-section is similar to that of an I-beam with a projection on top forming the tread of the rail.

Grooved Rail.—Same as "Girder Guard-rail." See "Guard-rail."

Guard-rail.—See "Guard-rail."

Guide Rail.—An additional rail placed inside of and close to one of the ordinary rails to prevent trains from leaving the track on curves.

Handrail.—A railing of concrete, stone, wood, or metal placed on top of posts or balusters to form an open-work construction. Used on the sides of bridges to prevent persons and animals from falling off.

Lorry Rail.—Same as "Lorry Track." See "Track."

Rail.

Pipe Rail.—A handrail, used on bridges, composed of wrought-iron pipe and fittings.

Relaying Rails.—Second-hand rails which are too much worn to carry heavy traffic at high speed and at frequent intervals, but with sufficient section left to serve for switch tracks, guard rails, etc.

Safety Rail.—A guard rail, *q.v.*

Strap Rail. –An iron strap bolted to a longitudinal wooden stringer to serve as a rail.

T Rail.—A rail having a section similar o the letter T.

Track Rail.—A rail composing a part of a track.

Rail-bender.—A mechanical device used for bending rails to a predetermined curvature before laying.

Rail-brace.—A knee casting attached to the railroad tie to prevent the spreading and overturning of rails, especially on curves and switches.

Rail-chair.—A metal block or shape used under a rail to give it a greater bearing on the tie.

Rail Clamp.—See "Clamp."

Rail-guard.—On English locomotives, a bar projecting down in front of the front wheel to within two inches from the rail to knock off any object which might be resting on the rail. Also sometimes used for "Guard-rail," *q.v.*

Railing.—See "Rail."

Rail Jack.—Same as "Track Jack." See "Jack."

Rail Joint.—See "Joint."

Rail-lift.—A device used on swing spans for lifting the ends of the rails thereon, so as to clear obstructions on adjacent spans as the draw is swung open.

Rail-lock.—A device used on swing spans for locking the rails at the ends of the span after closing the draw.

Railroad Curves.—See "Curves."

Railroad Jack.—Same as "Track Jack," *q.v.*

Railroad Spike.—Same as "Track Spike," *q.v.*

Rail Saw.—See "Saw."

Rail-section.—The cross-section of a rail.

Rail Spike.—Same as "Track Spike," *q.v.*

Rail Splice.—See "Splice."

Rail Tongs.—See "Tongs."

Railway Bridge.—See "Bridge."

Raising Hammer.—See "Hammer."

Rake.—The inclination to the vertical which a member of a bridge takes.

Ram.—The hammer of a pile driver; a heavy timber or bar used for driving pins in a bridge.

Battering Ram.—A beam of timber, generally having a metal head, used to drive home bridge pins. Sometimes it is made entirely of metal where a great many large pins are to be driven. A railroad rail is sometimes employed as a battering ram.

Hydraulic Ram.—An automatic device by which the fall of a comparatively large quantity of water is suddenly checked and a portion diverted to an air chamber. Owing to the momentum of the water, the air in the chamber is compressed, as the water enters, until the said momentum is absorbed. By the dropping of an outlet valve in the supply pipe a new flow is set up for a brief moment and again checked, causing an additional supply to enter the air chamber and renew or increase the previous pressure. This interior air pressure causes the water to pass out of the discharge pipe which ends at a higher elevation than the source of supply.

Rammed.—Driven with great force, as a pile is rammed into the ground by the blows of the hammer.

Ramp.—An inclined plane connecting two levels.
Random Bond.—See "Bond."
Random Course.—See "Course."
Random Masonry.—See "Masonry."
Random Rubble.—See "Rubble."
Random Tooled Dressing.—See "Dressing."
Range Masonry.—See "Masonry."
Range of Stress.—See "Stress."
Range Pole.—See "Pole."
Rankine's Formula.—One of the most widely known formulæ for the design and investigation of columns employed in engineering practice,

$$p = \frac{s}{1 + a\left(\frac{l}{r}\right)^2}$$

where p = allowable unit stress for the column,
s = allowable unit stress for short columns,
a = a constant,
l = length,
and r = radius of gyration in reference to an axis normal to a plane in which flexure takes place.

Rasp.—A coarse-cut file.
Flat Rasp.—A rasp having a narrow, rectangular cross-section.
Half-round Rasp.—A rasp having a semicircular cross-section.
Ratchet.—A mechanism consisting of a ratchet wheel and a pawl or pawls (or sometimes of a rack and pawl), so arranged that a movement of the pawl in one direction causes a partial revolution of the ratchet wheel while a reverse motion of the pawl has no effect thereon. It is often called a "Click."
Boat Ratchet, or Steamboat Ratchet.—An apparatus for pulling, consisting of a sleeve having internal, opposing threads at the ends and a ratchet and handle for turning the same. Suitably threaded rods with links and hooks at the outer ends screwed into the sleeve. The turning of the sleeve screws up on the rods causing them to approach each other.
Ratchet Coupling.—See "Coupling."
Ratchet Drill.—See "Drill."
Ratchet Jack.—See "Jack."
Ratchet Punch.—See "Punch."
Ratchet Reamer.—See "Reamer."
Ratchet Wheel.—See "Wheel."
Ratchet Wrench.—See "Wrench."
Rate of Strain.—See "Strain."
Rational Formula.—See "Formula."
Rat-tail File.—See "File."
Rattler.—A cylinder with ends closed, as in a barrel, set on trunnions for rotating. It is used for cleaning small castings by rolling and tumbling them over each other, and also for making abrasion tests of stone, brick, etc.
Rattling.—Working a rattler.
Raymond Pile.—See "Pile."
Rays.—The lines in a force diagram drawn from a selected pole to the ends of the several lines representing the forces in the load line. See "Force Diagram."
Reach.—The distance or limit within which a machine can operate, as the reach of a derrick. Also used to denote an unbroken stretch of a stream.
Reaction.—A passive force set up in opposition to an initial, active force, *e. g.*, the upward pressure on the bottom of a beam resting on a support, equal in amount to the downward pressure from the beam.

Reaction.

End Reaction.—The reaction set up at the end of a beam, girder, or truss by the loads thereon plus its own weight.

Negative Reaction.—A reaction caused by an uplift, and therefore acting in an opposite direction to a reaction caused by a direct load.

Positive Reaction.—A reaction caused by and opposed to a direct load.

Upward Reaction.—A reaction having an upward direction. This is generally the same as "Positive Reaction," *q.v.*

Real Horsepower.—Same as "Indicated Horsepower." See "Horsepower."

Ream.—To enlarge a hole by means of a cutting tool having fluted cutters on the side.

Reamer.—A tool having fluted sides with cutting edges used for enlarging holes. Also the machine that rotates the cutting tool.

Air Reamer.—A reaming machine operated by compressed air.

Close-quartered Reamer.—A pneumatic reamer having a cutting tool with a short shank, for working in restricted spaces.

Common Reamer.—A tapered bit with fluted sides and having sharp cutting edges.

Countersinking Reamer.—A bit with a conical-shaped cutting head, used for countersinking holes.

Expanding Reamer.—A reamer having a device that can be expanded after its insertion in a hole so as to make an undercut.

Flat Reamer.—A tapered, flat bit with chisel cutting edges.

Fluted Reamer.—Same as "Common Reamer," *q.v.*

Hand Reamer.—A reaming machine operated by hand.

Post Reamer.—Same as "Post-hole Auger," *q.v.*

Ratchet Reamer.—A reamer rotated by a ratchet mechanism.

Reaming.—Cutting with a reamer in order to enlarge rivet holes in steel.

Reaming-bit.—The cutting tool used with a reaming machine.

Reaming Iron.—A round, tapering tool with cutting edges for enlarging rivet holes. A reamer. An iron tool used to open the seams between planks, so that they may be more readily calked.

Rebate.—Same as "Rabbet," *q.v.*

Recarburization.—The adding of carbon in some form to metal partially decarburized in some steelmaking process in order to obtain the proper percentage of carbon in the finished product.

Receiving Valve.—See "Valve."

Reciprocal.—The quotient resulting from the dividing of unity by any quantity is the reciprocal of that quantity.

Reciprocate.—To move alternately back and forth.

Reconnoisance.—A preliminary investigation in the field for an engineering project.

Rectangle.—A plane, four-sided figure having four right angles and the opposite sides equal and parallel.

Rectangular Coordinates.—See "Coordinates."

Red Lead.—See "Lead."

Red Ochre.—See "Ochre."

Red Short.—A condition of brittleness in iron at red heat.

Red Short Iron.—See "Iron."

Reduced Load Contour.—A graphical means of representing the combination of different loads coming upon a structure, so as to give the value of the combination at any point by the ordinate to a curve known as the "Reduced load contour."

Reduced Scale.—See "Scale."

Reducer.—A pipe coupling for joining pipes of different sizes.

Reduction.—The production of metal from ore. Lessening in size.

Redundant Member.—See "Member."

Reef Knot.—See "Knot."

Reel.—A cylindrical drum, spool, or frame upon which is wound a rope, chain, or hose.

Reëntrant Angle.—See "Angle."

Reeve.—To pass a rope through a pulley block or an eye.

Reference Hub.—See "Hub."

Referencing.—A method of fixing the location of a line or point by measuring from it to some permanent object and recording such measuring for future recovery of the said line or point.

Refined Iron.—See "Iron."

Refuge-bays.—Platforms built on the side of a trestle or bridge so that men and hand-cars can be gotten out of the way of approaching trains. Also vertical recesses, large enough for several men to stand up in, left in the side of a wall adjoining a railroad track.

Refusal of Piles.—See "Piles."

Regenerative Furnace.—See "Furnace."

Regular Course.—See "Course."

Regular Curve.—See "Curve."

Re-heating.—Heating a second time; used in tempering steel.

Reinforced Concrete.—See "Concrete."

Reinforced Concrete Floor.—See "Floor."

Reinforcing Bar.—See "Bar."

Reinforcing Plate.—See "Plate."

Relaying Rails.—See "Rail."

Relieving Arch.—See "Arch."

Render.—Same as "Reeve," *q.v.*

Repair Link.—See "Link."

Repeated Stress.—See ' Stress."

Rephosphorization.—Adding phosphorus when too much has been removed during the manufacture of steel.

Replacing Switch.—See "Switch."

Repose.—Inaction. Rest.

Angle of Repose.—The angle of inclination to the horizontal of an inclined plane on which a body will be just upon the verge of motion.

Re-railing Guard.—See "Guard."

Reset.—To place in position a second time. The second set in mortar which has been disturbed after setting up the first time.

Residual.—Pertaining to or having the nature of a residuum. Remaining when all required constituents have been removed.

Residual Deformation.—See "Deformation."

Residual Shear.—See "Shear."

Resilience.—The amount of energy which can be stored in an elastic body, up to a given stress per square inch, and which can be given out again by the body as useful work.

Coefficient of Resilience.—The amount of energy absorbed per unit volume of the body. This is affected by the class of deformation whether axial, bending, or torsional; hence there are three kinds of coefficients of resilience.

Work of Resilience.—See "Work."

Resiliency.—The property possessed by an elastic body of absorbing energy as it is deformed and returning same when released.

Resilient.—Having resiliency.

Resistance.—The passive opposition or reaction to any action.

Axis of Resistance.—A line connecting the centres of resistance of successive sections of a member.

Resistance.

Bond Resistance.—The resistance offered to the slipping of a reinforcing bar when imbedded in concrete.

Centre of Resistance.—The point of application of the resultant of all the resisting forces.

Electrical Resistance.—That property of a body or conductor by virtue of which the passage of an electric current is opposed.

Line of Resistance.—Same as "Axis of Resistance," *q.v.*

Moment of Resistance.—The sum of the moments of all the resisting forces at a section of a member.

Tensile Resistance.—The ability of a member to resist elongation.

Ultimate Resistance.—The greatest resistance that a body can develop.

Uniform Resistance.—Resistance that is uniform over the whole cross-section.

Resistance Box.—See "Box."

Resistance Coil.—A coil of wire which offers a definite resistance to the passage of an electric current.

Resistance of Materials.—That property of bodies, due to molecular forces, by virtue of which they oppose the displacement of their molecules. The resistance which a body offers to distortion, or to deformation by an external force. Also called the strength of materials. This term is also applied to that branch of mechanics which deals with the phenomena of resistance.

Resisting Moment.—See "Moment."

Resolution.—The resolving of forces into their components.

Resolve.—To analyze a force into its several component forces according to the principle of the "Parallelogram of Forces," *q.v.*

Restitution.—The ability of an elastic body to recover from deformation due to impact.

Coefficient of Restitution.—The ratio of the total momentum after impact, to the total momentum before impact, in a system of colliding bodies.

Restoring of Steel.—See "Steel."

Rest Pier.—See "Pier."

Resultant, or **Resultant Force.**—A directed force having an effect equivalent to that of two or more other directed forces.

Resultant Stress.—See "Stress."

Retaining Wall.—See "Wall."

Retardation.—A decreasing of velocity, opposed to acceleration of velocity. Sometimes termed negative acceleration.

Re-tempering of Mortar.—See "Mortar."

Reticular.—Formed like a net; network.

Reticulated Bond.—See "Bond."

Return.—The termination of the drip-stone or hood-moulding of a door or window. A 180 degree bend in a pipe or conduit.

Reverberatory Furnace.—See "Furnace."

Reversal.—A change to the opposite kind, sign, pole, or direction.

Reversal of Stress.—See "Stress."

Reverse Curve.—See "Curve."

Revet.—To face the bank of a stream with wood, mattress, stone, or concrete to prevent erosion.

Revetment.—The facing of wood, mattress, stone, or concrete placed to prevent erosion.

Revolving Draw Bridge.—See "Bridge."

Rheostat.—An electrical instrument for regulating the amount of resistance in a circuit.

Rib.—An extra and external portion of a body giving it additional strength and stiffness. The truss or girder of an arch bridge.

Rib.

Arch Rib.—See "Arch."

Jack Rib.—Same as "Jack Rafter," *q.v.*

Stiffening Rib.—A rib run longitudinally along the curved trusses in a wooden bridge. Also the webs in a shoe, casting, or baseplate.

Rib-shortening.—The contraction in an arch rib due to the axial stress set up by the loading or by a rise in temperature.

Rich Lime.—See "Lime."

Rig.—To fit out with what is needed. To put a machine in condition for using.

Rigging.—The ropes, pulley-blocks, etc. needed to fit out a derrick or similar machine.

Right Arch.—See "Arch."

Right Forward.—The American method of building a skew arch by constructing a number of short right arches adjoining each other, each one springing from a skewback which is ahead of or back of its neighbor. This is to avoid the use of spiral joints between the voussoirs, a construction which prevails in European practice.

Right-handed Nut.—Any nut having a right-handed thread.

Right-handed Screw.—See "Screw."

Right-handed Thread.—See "Thread."

Righting Moment.—See "Moment."

Right-line Formula.—A column formula in which the allowable unit working stress is made to vary as the first power of $\frac{l}{r}$ thus—

$$p = a - b\,\frac{l}{r}.$$

where p = allowable working stress,
a = allowable unit stress for short columns,
b = a constant.
l = length,
and r = the least radius of gyration.

Right of Way.—The land or water rights necessary for the roadway and its accessories.

Rigid.—Resisting change of form; stiff; firm; not pliant or flexible.

Rigid Body.—A body possessing rigidity or stiffness.

Rigidity.—The quality of being rigid or resistant to distortion.

Relative Rigidity.—A comparison of the rigidities of two bodies.

Rim Bearing.—See "Bearing."

Rim-bearing Draw.—See "Draw."

Rim-bearing Turntable.—See "Turntable."

Rim Saw.—See "Saw."

Rind-gall.—A defect in timber due to a bruise in the bark that causes a hard spot in the wood to which the succeeding layers of wood do not adhere.

Ring.—A solid generated by the revolution of a closed curve about an axis in the plane of the said curve, but lying outside thereof.

Arch ring.—See "Arch."

Guy Ring.—A ring attachment on a derrick, etc., for connecting guy lines.

Packing Ring.—An elastic metallic ring used for packing the piston of an engine.

Pile Ring.—Same as "Pile Band," *q.v.*

Ring Bolt.—Same as "Eye Bolt," See "Bolt."

Ring Chain.—A chain having rings at the ends and often one or more intermediate ones.

Ring Course.—See "Course."

Ring Dog.—See "Dog."

Ring Dolly.—See "Dolly."

Ring Heart.—See "Heart."

Ring Joint.—See "Joint."

Ring Shake.—See "Shake."

Ring Stones.—Same as "Voussoirs," *q.v.*

Riprap.—A facing of stone, concrete, or planks placed on the bank slope of a stream or around a pier to prevent erosion.

Rip Saw.—See "Saw."

Rise.—The vertical distance between two treads in a stairway.

Rise of an Arch.—See "Arch."

Risers in Moulds.—An excess of metal above the casting proper. Its purpose is to keep the mould full while the metal is hardening.

River Gravel.—Smooth, rounded stones, varying in size from sand particles to pebbles several inches in diameter.

Rivet.—A short iron or soft steel rod with a head at one end. It is heated and put into a proper hole, and the other end is hammered down until a suitable head is formed.

Calked Rivet.—A rivet which has not been properly driven so as to fit tightly in the hole, but to which a seeming tightness has been given by turning the edge of the head under with a cold cut or similar tool.

Countersunk Rivet.—A rivet used in countersunk holes in which the point, while hot, is hammered down to fill the countersinking.

Field Rivet.—A rivet driven in the field during the erection of a steel structure.

Flat-head Rivet.—A rivet which has the point hammered flat instead of rounding.

Grip of Rivet.—The thickness of the plates or parts through which the rivet passes.

Pitch of Rivets.—The distance between the centres of adjacent rivets in the same line.

Plugged Rivet.—Same as "Calked Rivets," *q.v.*

Shop Rivets.—A rivet driven in the shop.

Snap-head Rivet.—A rivet having its head formed by a snap.

Stitch Rivets.—Rivets placed at intervals between two component parts to hold them together and give lateral stiffness.

Rivet Cutter.—See "Cutter."

Riveted Girder.—See "Girder."

Riveted Joint.—See "Joint."

Riveted Truss.—See "Truss."

Riveter.—One who drives rivets. A riveting machine.

Air Riveter.—A riveting machine which is operated by compressed air.

Alligator Riveter.—A jaw riveter worked by the action of a cam, used in shopwork.

Bull Riveter.—A form of stationary, yoke riveter set in a vertical position and having a large air cylinder at the end of one of the arms. The piston moves with a short stroke in a horizontal direction and the former on the end of the piston rod upsets the shank and forms the head in one movement of the piston.

Horseshoe Riveter.—A form of yoke riveter hung from a travelling crane, so as to be readily moved about the shop to reach different parts of a job.

Hydraulic Riveter.—A riveting machine operated by water under pressure.

Pneumatic Riveter.—Same as "Air Riveter," *q.v.*

Steam Riveter.—A shop riveter driven by steam.

Toggle Riveter.—A riveting machine using a toggle mechanism to give the pressure required to upset the stem and form the rivet head.

Yoke Riveter.—A machine riveter in which the hammer is attached to one end of an elongated, narrow yoke and to the anvil at the other, the yoke permitting the reaching of rivets remote from the edge of the plates to be riveted.

Rivet Forge.—See "Forge."

Rivet Hammer.—See "Hammer."

Rivet-hole.—The hole through which a rivet is driven or to be driven.

Riveting.—The fastening of plates or parts together by means of rivets.

Riveting.

Butt Riveting.—The making of a butt-joint by using cross-plates and rivets.

Chain Riveting.—A term applied to riveting where the rivets in the second or succeeding rows are placed directly back of those in the first row or preceding rows.

Cross Riveting.—Same as "Staggered Riveting," *q.v.*

Double Riveting.—A term applied to riveted joints in which a double row of staggered rivets is used for a lap joint and two double rows for a butt joint—one double row on each side of the joint.

Hand Riveting.—Driving rivets by hand.

Lap Riveting.—The making of a lap-joint by using rivets to fasten the overlapping ends of the plates.

Single Riveting.—A term applied to lap-joints in which one row of rivets only is used to fasten the plates.

Staggered Riveting, or Zigzag Riveting.—Rivets set in zigzag order, or so spaced that the rivets in one row are opposite the centres of the spaces of the adjoining rows.

Riveting Burr.—See "Burr."

Riveting Gang.—See "Gang.'

Riveting Gun.—See "Gun."

Riveting Kit.—See "Kit."

Rivet Rod.—See "Rod."

Rivet Set.—Same as "Rivet Snap." See "Snap."

Rivet Snap.—See "Snap."

Rivet Steel.—See "Steel."

Rivet-stem.—The shank or that portion of the rivet under the head.

Rivet Tongs.—Tongs used by field riveters for throwing and placing hot rivets.

Road-bed.—In railroading the finished surface of the roadway on which the ballast and track rest. In highways that of the roadway which receives either the concrete base or the broken stone.

Road Roller.—See "Roller."

Roadway.—That part of the road over which the vehicles pass.

Clear Roadway.—The horizontal distance, measured perpendicularly to the plane of the trusses, between the inner edges of the batter braces. Sometimes measured between the faces of curbs or guard rails.

Rock Drill.—See "Drill."

Rocker.—A casting or built-up steel frame fastened to the end of a truss or column to permit of a slight rotation.

Rocker-arm.—An arm on a rock shaft, as in the valve mechanism of a steam engine.

Rocker Bearing.—See "Bearing."

Rocker Bent.—See "Bent."

Rocker End.—The end of a truss or column resting on a rocker.

Rock-faced Dressing.—See "Dressing."

Rock Movement.—A slipping movement of a ledge of rock, usually caused by water in the horizontal seams.

Rock Shaft.—See "Shaft."

Rock Work.—A general term for "Masonry," *q.v.* Also see "Work."

Rod.—A long, round piece, strip, or bar of metal. A surveyor's tool for finding the difference in elevation between two points, used in connection with a level. As ordinarily constructed, it consists of two flat strips of wood, arranged to slide upon each other and having the exposed faces graduated into feet and tenths, or in some cases, feet, inches, and fractions of an inch.

Architect's Rod.—A very light and simple sliding level rod having two equal parts each seven-eighths of an inch square. When closed it is about five and a half feet long. It carries a target and is graduated into feet, inches, and fractions of inches.

Rod.

Beam Trussing Rods.—Rods which are run beneath the tension side of a beam to form, in connection with one or more struts, a system of trussing to strengthen the said beam.

Boston Rod.—A leveling rod in which the target is fixed to the sliding part of the rod. This is raised or lowered by the rodman until the target is in the line of sight, then clamped and read by the rodman by means of a scale on its face.

Connecting Rod.—A steel rod connecting the cross-head and the crankpin in an engine.

Cross-section Rod.—A rod for measuring horizontal distances. Graduated in feet and tenths, with the figures so placed as to be read easily when rod is horizontal. It is provided with a level bulb so that it can be leveled.

Eccentric Rod.—The main connecting link by which the motion of an eccentric is transformed and transferred.

Giasticutus Rod.—A term (perhaps unauthorized, but formerly in common use among bridge builders) to denote a small horizontal rod connecting the middle points of two adjacent posts of the same truss, for the professed purpose of fixing or holding the posts at the middle in order that they may be figured for half length. The benefit derived therefrom is more imaginary than real.

King Rod.—An iron rod used to take the place of a king post.

Lateral Rod.—A tension diagonal of a lateral system.

Leveling Rod.—A surveyor's graduated rod. See "Rod."

Metric Rod.—A level rod graduated in meters and decimal parts thereof.

New York Rod.—A level rod having two sliding parts and a movable target. It is engine-divided into feet and decimal parts thereof. The graduations are fine lines burned into the hard wood and can be read direct only for very short sights, thus necessitating the setting of the target. This rod is used for precise work.

Philadelphia Rod.—A level rod having two sliding parts and a movable target. The graduations are painted on as well as the numbers; and the rod can, therefore, be read at considerable distances without setting the target. Where great precision is not required, this rod is well adapted for rapid work.

Piston Rod.—A steel rod connecting the piston with the cross-head of an engine.

Plain Rod.—A level rod made of one piece of wood with figures on one side and graduated in feet and decimal parts thereof.

Portal Rod.—A tension member in the portal bracing of a truss. This is an antiquated type of construction.

Radial Rod.—A rod connecting the roller of a rim-bearing draw-span with the centre casting.

Rivet Rod.—A bar of soft iron or steel from which rivets are made.

Sounding Rod.—A rod or pipe used for making soundings by pushing or driving it into the soil.

Spider Rod.—Same as "Radial Rod," *q.v.*

Stadia Rod.—A rod divided into feet and tenths with special markings which are visible at long distances. It is used in connection with the stadia wires of the transit to read distances directly. Sometimes a level rod is employed as a stadia rod. Special stadia rods are frequently termed stadia boards.

Stay Rod.—A stiffening rod used in the interior of a boiler or cylinder.

Suspension Rod.—One of the rods attached to the cable of a suspension bridge to support the floor system.

Sway Rod.—Any rod used for sway-bracing.

Telemeter Rod.—Same as "Stadia Rod," *q.v.*

Tension Rod.—Any rod subjected to tension.

Tie Rod.—A rod connecting two parts of a structure. The tension rod in a wooden Howe truss bridge. Also a bar or rod used to connect the two rails in a railway track to prevent their spreading.

Rod.

Troy Rod.—A level rod made of two sliding pieces and carrying two targets, one on the top and the other on the bottom, the upper target being fixed to the extension member and the lower target arranged to move on the main rod.

Truss Rod.—A rod used for trussing or bracing a beam, also called Hog Chain. Any rod employed as a part of a truss.

Upset Rod.—A rod having one or both of its ends enlarged by an upsetting process.

Vibration Rod.—A tension diagonal for vertical or portal sway-bracing used in light highway bridges. Such bracing is far inferior to rigid sway-bracing.

Rodman.—The man in a level party who carries and manipulates the level rod.

Rolled Beam.—See "Beam."

Rolled Channel.—See "Channel."

Rolled Iron.—See "Iron."

Rolled Pile.—See "Pile."

Rolled Steel.—See "Steel."

Roller.—Any short, round bar put under an object to facilitate its movement.

Conical Roller.—A cone-shaped roller placed under an object in order to provide for its rotating motion. Used under rim-bearing swing spans.

Expansion Rollers.—A group of steel cylinders nested in a box or suitable frame placed under the shoe of a span to facilitate its movement during temperature changes and loading.

Friction Rollers.—Rollers placed between moving bodies or around a revolving shaft to reduce the friction.

Guide Rollers.—A roller on a fixed axle serving as a guide to anything passing along in contact with it.

Indentation Roller.—A hand tool for roughening concrete surfaces, consisting of a roller with teeth mounted in a frame attached to a handle.

Road Roller.—A heavy steam or horse roller used in the construction of macadamized roads and pavements.

Segmental Roller.—A roller composed of two opposing circular segments and an intermediate connecting web; used under bridge-shoes.

Roller-and-thimble Chain.—See "Chain."

Roller Bascule.—See "Bascule."

Roller Bearing.—See "Bearing."

Roller-bearing Bascule.—See "Bascule."

Roller Box, or Roller Frame.—See "Box."

Roller Plate.—See "Plate."

Rolling Draw Bridge.—Same as "Pull-back Draw Bridge." See "Bridge."

Rolling Friction.—See "Friction."

Rolling Hitch Knot.—See "Knot."

Rolling Lift Bridge.—See "Bridge."

Rolling Load.—Same as "Moving Load." See "Load."

Rolling Mill.—Same as "Mill," *q.v.*

Rolling Stock.—All of the various classes of cars and engines used on a railroad.

Roll Rack.—See "Rack."

Rolls.—A machine consisting of several rollers, mounted in a frame, having intermeshing gears producing a positive motion; used in shaping steel ingots into bars, beams, angles, etc.

Puddle Rolls.—A machine having heavy, grooved rollers, between which lumps of plastic iron, taken direct from the puddling furnace and hammered into rough bars, are first rolled.

Straightening Rolls.—Rolls in a steel mill used for rerolling bars, beams, channels, etc., which had been bent during manufacture.

Roman Cement.—See "Cement."

Roof Truss.—See "Truss."
Root of Gear Tooth.—See "Tooth."
Rope.—Strands of wire, hemp, cotton, flax, etc., twisted in a smooth, flexible cord of at least one-half inch in diameter.
Guide Ropes.—Ropes used as guides for a hoisting cage.
Guy Rope.—A rope used as a guy-line, *q.v.*
Hoisting-cable Rope.—A wire rope roven through a suspended block or a fixed block in the top of a mast of a derrick and fastened to the drum of a hoisting engine. Used to raise weights.
Manila Rope.—Rope made from the fibre of the *Musa textilis*, a tall perennial herb of the same genus as the banana, which grows in the Philippine Islands.
Sisal Rope.—Rope made from sisal hemp.
Standing Rope.—A rope fastened permanently, as a guy for a derrick.
Wire Rope.—A rope made of small strands of twisted wire often with a cotton or hemp centre.
Rope Bridge.—See "Bridge."
Rope Clamp.—See "Clamp."
Rope Guard.—See "Guard."
Rope Lashing.—See "Lashing."
Rope Sling.—See "Sling."
Rose Bit.—See "Bit."
Rose Drill.—See "Drill."
Rose Jet.—See "Jet."
Rosendale Cement.—See "Cement."
Rosette.—An ornamental device resembling a rose in bloom.
Rot.—Decay, decomposition.
Dry Rot.—A decay affecting dry timber, caused by a fungus growth.
Wet Rot.—A decay affecting timber, caused by alternate wetting and drying.
Rotary Crane.—See "Crane."
Rotary Furance.—See "Furnace."
Rotary Pump.—See "Pump."
Rotating Draw.—Same as "Revolving Draw Bridge." See "Bridge."
Rotating Drill.—See "Drill."
Rotation.—Turning around on an axis or centre. Rotary motion.
Axis of Rotation.—A line passing through the centre of rotation and perpendicular to the plane of rotation.
Centre of Rotation.—The point of a rotating body which remains at rest while all the other points revolve around it.
Negative Rotation.—Rotation in a direction opposite to that of the hands of a clock.
Positive Rotation.—Rotation in the same direction as that of the hands of a clock.
Rotten Knot.—See "Knot."
Rough Ashlar.—See "Ashlar."
Rough Dressing.—See "Dressing."
Rougher.—A man or a machine that does the preliminary work or roughing out of an object.
Rough Finish.—See "Finish."
Rough-pointed Dressing.—See "Dressing."
Round Knot.—See "Knot."
Round Pile.—See "Pile."
Rounds.—Round bars in the bracing system of a highway bridge. The rungs of a ladder.
Round Turn and a Half Hitch.—See "Knot."
Rowlock Bond.—See "Bond."
Rubbed Dressing.—See "Dressing."

Rubbed Stone.—Same as Rubbed Dressing. See "Dressing."
Rubber.—A man or a machine that smooths stone. An elastic gum.
Kneaded Rubber.—A pliable eraser used to clean drawings.
Rubber Hose.—See "Hose."
Rubber Packing.—See "Packing."
Rubble.—Rough, broken, one-man-size stone used in rubble masonry.
Broken Coursed Rubble, or **Broken Range Rubble.**—Rubble masonry laid in partial courses and having abrupt changes in thickness thereof.
Coursed Rubble.—Rubble masonry laid in courses which may or may not vary in thickness.
Random Rubble or **Uncoursed Rubble.**—Rubble masonry laid up without regard to courses.
Rubble Masonry, or **Rubble Work.**—See "Masonry."
Ruff.—An annular ridge formed on a shaft or other piece, commonly at a journal, to prevent motion endwise.
Rule.—A flat, straight stick or strip of metal graduated into linear units for convenience in measuring or laying off distances.
Shrink Rule.—A rule having slightly exaggerated divisions (an excess of one-eighth of an inch in twelve inches) to compensate for the shrinkage of metal in cooling. Used by pattern makers.
Slide Rule.—See "Slide-rule."
Rule Joint.—See "Joint."
Run or **Runway.**—A line of planks laid down for wheeling or walking over. Used by constructors.
Rundle.—The step of a ladder. Same as round.
Rung.—The round or step in a ladder.
Rung-head.—The upper end of a floor timber.
Runner.—In foundry practice, the channel through which molten metal is run into the mould.
Running Block.—See "Block."
Running-expense.—Expenditures incurred during the operation of the plant or structure only. They are equal to the sum of operation and maintenance outlays.
Running Hitch.—A form of "Running Knot." See "Knot."
Running Knot.—See "Knot."
Run-off.—The water which flows from a drainage basin.
Runway.—A passageway. Also see "Run."
Rupture.—To break apart. The act of breaking apart.
Angle of Rupture.—The angle made with the transverse axis by the break in a test piece.
Joint of Rupture.—That joint in a voussoir arch for which the tendency to open at the extrados is the greatest.
Modulus of Rupture.—The unit stress at which a piece fails.
Plane of Rupture.—The plane along which failure occurs.
Rupture Line.—See "Line."
Rust.—An oxidization of a metal.
Iron Rust.—The oxide of iron.
Rust Cement.—See "Cement."
Rustic or **Rusticated Dressing.**—See "Dressing."
Rust Joint.—See "Joint."

S

Sack.—A bag. To discharge an employee.
Gunny-sack.—A bag made of coarse, heavy sacking of jute or hemp.

Saddle.—A block having its top hollowed for carrying a rounded member. A block at the top of the tower of a suspension bridge over which pass the suspension cables or chains.

Saddle Head.—See "Head."

Saddle Joint.—See "Joint."

Safe Load.—See "Load."

Safety-factor.—The ratio of ultimate load to the greatest allowable working load. This term is losing favor with engineers, as its use has been abused. There is no such thing as a factor of safety for a well proportioned bridge, for each member should have an intensity of working stress proportional to the character and amount of work which it has to perform. This is best accomplished by adding to the live load stress a certain varying proportion thereof to allow for the effect of impact.

Safety Rail.—A guard rail, *q.v.*

Safety-stop.—An automatic device on a hoisting apparatus designed to prevent the machine from falling in case the ropes or the machinery should break.

Sag.—The greatest deviation from a straight line joining its ends which a flexible body undergoes, such as a rope or a chain.

Sal-ammoniac.—Commerical ammonium chloride.

Salient.—A portion projecting beyond the general line of the structure.

Salt.—Chloride of sodium (NaCl). Used in mixing concrete in freezing weather to lower the freezing point of the mixture. A compound of basic and acid substances.

Salvage.—That portion of a structure or plant that can be saved from destruction after having been used.

Salvage-value.—The price for which a structure or a plant is sold second-hand.

Sampling-iron.—An iron bit or spoon for making a hole in a barrel and pulling out a sample of the contents. Used by cement testers.

Sand.—Broken down, water worn, crystalline rocks of a size less than one-tenth of an inch in diameter.

Coarse Sand.—Sand rejected by a number twenty sieve.

Fine Sand.—A sand containing more than thirty per cent of particles that will pass a No 40 sieve. Usually undesirable for concrete.

Green Sand.—A sand fresh from the pit. Unburned moulding sand.

Iron Sand.—Sand containing considerable quantities of small particles of iron ore.

Quick Sand.—A fine, smooth-grained sand. When wet, it is very unstable.

Sharp Sand.—A sand having sharp-edged grains or particles.

Slag Sand.—Slag ground to the consistency of sand and used to replace sand for mortar or concrete.

Sand-bag.—A bag filled with sand, used to close a gap through which water is flowing.

Sand Bar.—See "Bar."

Sand Bearing.—See "Bearing."

Sand-blast.—A device for projecting sand particles, at a high velocity, through a nozzle by means of compressed air. Used in cleaning metal.

Sand Briquettes.—See "Briquettes."

Sand Cement.—See "Cement."

Sand-hog.—A term applied to any laborer working under compressed air in the sinking of piers.

Sand-hog House.—A house near the bridge site, used by sand-hogs between shifts.

Sand Hoist, or Sand Lift.—See "Hoist."

Sand Pile.—See "Pile."

Sand Pump.—See "Pump."

Sand Screen.—See "Screen."

Sand Sieve.—See "Sieve."

Sandstone.—See "Stone."

Sand Trap.—See "Trap."

Sandwich Girder.—See "Girder."

Sap.—The fluid which circulates in plants, trees and other vegetation. Also applied to moisture in newly quarried rock. Same as "Quarry Sap," *q.v.*

Sappy.—A condition of steel as indicated by the surface of fracture where the grains are very coarse and bright.

Sap Tie.—See "Tie."

Sap Wood.—See "Wood."

Sash Brace.—A horizontal member secured to the posts or piles of a bent between the cap and sill.

Saw.—A cutting tool consisting of a thin blade or sheet of steel having teeth on one or both edges and handles or other attachments for giving it motion.

Band Saw.—An endless, narrow band or ribbon of steel with a serrated edge, passing over two large wheels which give it a continuous uniform motion instead of the reciprocating action of a jig-saw, also called a "belt saw" or "endless saw."

Buzz Saw.—A circular saw; so called from its sound when in action.

Circular Saw.—A thin circular plate of steel, with teeth cut in the edge, mounted on a shaft and rotated at a high speed.

Cold Saw.—A toothless, soft-iron disk rotating at a high speed, used in mills for cutting steel beams.

Cross-cut Saw.—A saw adapted by the filing and setting of its teeth to cut across the grain of the wood.

Hack Saw.—A small frame hand saw having a narrow blade with fine teeth set close together and well tempered. Used for sawing metals.

Hand Saw.—A saw consisting of a blade of steel with a serrated edge, and having a handle at one end adapted for use by one hand.

Hot Saw, or Iron Saw.—A circular saw for hot steel or iron shapes.

Jig Saw.—A reciprocating sawing machine having a narrow vertical blade set in a frame which has an oscillating motion.

Metal Saw.—A saw having a blade tempered hard enough to cut metals.

Pit Saw.—A large hand saw worked vertically by two men, one of whom (the pitman) stands in a pit.

Rail Saw.—A saw used at the mills for cutting rails.

Rim Saw.—A type of circular saw in which the teeth are a part of a detachable ring that is mounted on a central disk.

Rip Saw.—A saw having teeth with small set and large rake used for sawing along the grain of timber.

Stone Saw.—A tool or machine for cutting stone, consisting of a flat blade of iron having a reciprocating motion, and fed with sand by a stream of water, the sand doing the cutting.

Wide Cross-cut Saw.—A cross-cut saw with a long, wide blade having a handle on each end so that it can be operated by two men.

Scab.—A plank used in making a splice between two timbers.

Iron Scab.—A scab or scab-plate made of iron.

Scabbed.—The condition of being joined by a scab or scabs.

Scabbing Hammer.—See "Hammer."

Scabbled Dressing.—A form of "Masonry Dressing." See "Dressing."

Scab Plate.—Same as "Scab," *q.v.*

Scaffold.—A temporary platform or staging for supporting workmen during the building of a structure.

Swinging Scaffold.—A scaffold hung on ropes fastened to overhead supports.

Scaffolding.—A general term covering all the scaffolds on a job.

Scale.—A graduated stick of wood or metal for measuring or laying off distances. To measure with a scale. The ratio of the linear dimensions of a drawing to the corresponding dimensions of the actual object so represented. A coating of oxide which forms on the surface of heated metal.

Architects' Scale.—A scale in which the units are divided duodecimally.

Scale.

Engineers' Scale.—A scale in which the units are divided decimally.

Enlarged Scale.—An oversized delineation of an object.

Exaggerated Scale Drawing.—A drawing on which two scales are used, as a railroad profile. But little used by bridge engineers.

Flat Scale.—A scale made on a flat stick, strip of metal, or cardboard.

Hammer Scale.—A scale of oxide which forms on bars when heated.

Iron Scale.—A loose coating of oxide which forms on heated iron during the process of forging.

Natural Scale.—A full-sized delineation of an object. Sometimes used for "Unexaggerated Scale."

Reduced Scale.—An undersized delineation of an object.

Triangular Scale.—A scale made on a triangular shaped stick, permitting of six different sets of graduations.

Unexaggerated Scale.—A term used to denote that the scale used in making a drawing is the same in all directions.

Scaling Hammer.—See "Hammer."

Scarf Joint.—See "Joint."

Scarf Weld.—See "Weld."

Scarp.—A steep slope.

Schedule-prices.—The prices stipulated in a contract for the performance of labor or the furnishing of materials at unit rates. Called also "Unit Prices."

Schwedler Truss.—See "Truss."

Scoop.—A special type of bucket having a cutting edge on the front side, used in dredging. A spade having the sides turned up.

Scoop Dredge.—See "Dredge."

Scooping.—The act of dredging with a scoop.

Scotch.—To chip; to hack. To block, or prop up.

Scour.—A clearing out or removal of silt and sand in the bed of a stream by a strong current. To remove such material in that manner.

Scow.—A flat-bottom boat.

Dump Scow.—A drop-bottom scow from which material is dumped.

Scrag.—To straighten a spring, etc., which has been bent, by pushing in the bulge and releasing.

Scrap.—Discarded material. Junk.

Scraper.—A tool for scraping up loosened earth and hauling it away; drawn by horses or mules and guided by handles attached to its rear.

Scrap Iron.—See "Iron."

Scrap Pile.—A heap or a pile of junk.

Scratch Awl.—See "Awl."

Screeds, or Screed-iron.—Strips of wood used for gauges for the finish of plastering. An angle iron on legs, or other device, which, in concrete work, is set on the slab form to serve as a guide in forming the top of the slab.

Screen.—A large sieve; device for sifting and separating particles of different sizes.

Sand Screen.—A sieve for sifting sand.

Screening.—The act of sifting and separating particles by a screen. Also applied to the material passing throu h the screen—generally used in the plural.

Granite Screenings.—Small particles of granite screened from the larger.

Screw.—A cylindrical bar on which has been formed a helical projection or thread.

Cap Screw.—A screw which has a square or hexagonal head larger than the shank of the screw, thereby providing a shoulder for bearing. It is turned with a wrench.

Female Screw.—A hollow cylinder having an interior thread. A nut.

Guide Screw.—A screw for directing or regulating certain movements in machinery.

Jack Screw.—Same as "Screw Jack." See "Jack."

Screw.

Lag Screw.—A large-sized wood screw with a square head larger than the shank for convenient turning with a wrench, and having a special thread to increase the holding power.

Left-handed Screw.—A screw having a left-handed thread. See "Thread."

Machine Screw.—A screw which has a straight shank and an enlarged head providing a shoulder for bearing. A slot in the head affords the means for turning with a screwdriver.

Male Screw.—A screw having an exterior thread.

Micrometer Screw.—Same as "Micrometer," *q.v.*

Right-handed Screw.—A screw having a right-hand thread. See "Thread."

Set Screw.—A type of screw similar to a cap screw but without a shoulder under the head and with a cup-shaped end for a better grip on the object.

Square-threaded Screw.—Any screw having square threads.

Thumb Screw.—A screw having flat wing-like projections on the head for convenience in turning with thumb and fingers.

Wood Screw.—A screw having a tapering shank and either a flat or a rounded head with a slot for turning by means of a screwdriver.

Screw-adjustment.—An adjustment in which motion is provided by a screw.

Screw Bolt.—See "Bolt."

Screw Clamp.—See "Clamp."

Screw Disc.—See "Disc."

Screw Dolly.—See "Dolly."

Screw-end.—The threaded end of a bolt.

Screw Jack.—Same as "Jack Screw," See "Jack."

Screw Stock.—Same as "Die Stock." See "Stock."

Screw Pile.—See "Pile."

Screw Thread.—The thread on a screw.

Screw Track-spike.—See "Spike."

Scribe.—To trim off the edge of a board, etc., so as to make it fit closely at all points to a certain line; to mark with a scriber.

Scriber.—A sharp-pointed tool for marking metal.

Scribing Awl.—See "Awl."

Scrids.—Same as "Screeds."

Scurf.—To flake off, or the material which flakes off. Dross.

Seam.—A crack in a badly rolled steel section. A crack or parting in rock.

Crow-foot Seam.—A vein in rock containing dark-colored, uncemented material.

Dry Seam.—An open crack in a rock.

Lap Seam.—A seam in which the separate parts extend over each other.

Seasoning.—The process of becoming fit for use, as lumber becoming dry and hard through exposure.

Seat Angle.—See "Angle."

Secant.—Any line cutting another line. A trigonometric function defined by the ratio of the hypothenuse of a right-angled triangle to its base, in reference to the acute angle adjacent to the said base.

Second-class Masonry.—See "Masonry."

Secondary Member.—See "Member."

Secondary Stress.—See "Stress."

Secondary Strut.—See "Strut."

Secondary Truss.—See "Truss."

Secondary Truss Member.—See "Member."

Second Set.—See "Set."

Section.—The trace on a secant plane made by the object cut. Sometimes improperly used for a member or segment thereof.

Section.

Cross-section.—A section made by a secant plane perpendicular to the axis of the member, structure, or any construction.

Dangerous Section.—That section or position where failure of a member is most likely to occur.

Fracture Section.—The section at which failure occurs.

Gross Section.—Same as "Total Section," *q.v.*

Horizontal Section.—A section made by a horizontal secant plane.

Lateral Section.—A section made by a secant plane parallel to the side of an object.

Longitudinal Section.—A section made by the secant plane passing parallel to the long axis of the member.

Meridian Section.—A section of a sphere made by a plane passing through and containing a diameter.

Net Section.—Used improperly for the net area of a section; *i. e.*, the available area of a member after the rivet-hole areas are deducted.

Star Section.—A section of a member having the shape of a four-pointed star.

Transverse Section.—Same as "Cross-section," *q.v.*

Uniform Section.—The condition of having the same section for all parallel positions of the secant plane.

Sectional Area.—See "Area."

Section-modulus.—The moment of inertia of the area of a section of a member divided by the distance from the centre of gravity to the outmost fiber.

Section Required.—The section area of a member required properly to resist the total force acting on the said member.

Sector.—That portion of a circle included between two radii and the subtending arc.

Sediment.—The fine material which settles to the bottom of water or other liquid.

Seepage.—The oozing or percolation of water through a material. Water which has thus percolated.

Segment.—That portion of a circle lying between an arc and its chord. A portion of a member.

Track Segment.—A part or unit of a circular track used to carry the rollers of a rim-bearing draw-span.

Segmental.—Pertaining to a segment.

Segmental Arch.—See "Arch."

Segmental Roller.—See "Roller."

Seize.—To bind a journal in its bearings by overheating. To fasten or bind by turns or windings of cord, line, or small rope.

Self-hardening Steel.—Same as "Mushet Steel," *q.v.*

Semaphore.—An apparatus for making signals with movable arms.

Semi-cantilevering.—A method of erecting a span without falsework, by cantilevering from an adjacent span, or adjacent spans, or from a rock bluff by toggles, and afterward removing these so as to leave the structure as a simple span.

Semi-circular.—Pertaining to the half of a circle.

Semi-intrados.—Half of an intrados. See "Intrados."

Semi-polar Coordinates.—See Coordinates.

Separators.—Small, cast-iron, wheel-like blocks, used to separate stringers in trestles, or the timbers that form the chord sections of a Howe truss bridge.

Set.—A condition of hardening exhibited by cement after mixing with water. The permanent change or deformation which a material subjected to stress undergoes when its elastic limit is exceeded. An outfit of tools. A tool for shaping rivet heads.

Button Set.—A rivet set or snap, giving a button shape to the rivet head.

Set.

Final Set, or Hard Set.—The degree of hardening of cement mortar as determined by the non-penetration of the Vicat needle.

Initial Set.—The beginning of the hardening process of cement mortar as determined by the Vicat needle.

Permanent Set.—Same as "Hard Set" in cement, *q.v.* Also the residual deformation in a member when the load is removed.

Rivet Set.—A tool for shaping the heads of rivets. Often called a snap.

Second Set.—The hardening of mortar that has once partially hardened and which has been disturbed before getting its final set.

Set Pin.—Same as "Dowel," *q.v.*

Set Screw.—See "Screw."

Sewer Brick.—See "Brick."

Shackle.—A U-shaped attachment for large pulley-blocks replacing the customary hook.

Anchor Shackle.—A bolt or clevis with two eyes and a screw bolt and key, used for securing a cable to the ring of an anchor; also employed for coupling chains.

Splicing Shackle.—A shackle in the end of a length of chain through which the end of a rope is taken and spliced.

Shackle Bar.—See "Bar."

Shackle Joint.—See "Joint."

Shade.—A painter's term descriptive of that difference between colors which results from a variation in luminosity only, the other color constants being essentially equal.

Shaft.—A well-like opening, nearly or quite vertical, in cribs and caissons; used for hoisting material through or for the passage of workmen. A long, cylindrical bar capable of rotating and transmitting torque.

Air Shaft.—A tube, pipe, conduit, or passageway for conveying air.

Cam Shaft.—A shaft on which a cam is mounted.

Crank Shaft.—A shaft having one or more cranks attached.

Driving Shaft.—A shaft from the driving wheel communicating motion to machinery.

Excavating Shaft.—A shaft or hole through which excavation is carried on.

Jack Shaft.—In rolling-mill machinery, a shaft that takes the power from the engine shaft and transmits it by pinions and spindles to the rolls.

Junction Shaft.—A spindle in a rolling mill.

Main Shaft.—A principal shaft used in the transmission of power.

Pinion Shaft.—A shaft carrying a pinion for transmitting motion.

Rock Shaft.—A shaft which makes part of a revolution each way instead of rotating continuously in the same direction.

Supply Shaft.—A passageway in a crib and caisson for the transferring of supplies.

Working Shaft.—A passageway in a crib and caisson for workmen.

Worm Shaft.—The shaft or axle passing through a worm.

Shaft Bearing.—See "Bearing."

Shaft Coupling.—See "Coupling."

Shafting.—A general term for a number of shafts connected up to form a system. Rounds used for making shafts.

Cold-rolled Shafting.—Shafting on which the final rolling was done after the metal had somewhat cooled.

Turned Shafting.—Shafting which has received its truing-up and final finish by being turned in a lathe.

Shafting Box.—See "Box."

Shakes.—Splits or checks in timber which usually cause a separation of the wood between the annular rings.

Heart Shake.—A fissure in the heart of a timber due to growth.

Shakes.

Ring Shake.—Same as "Ring Heart," *q.v.*, except that the cleavage occurs nearer the bark.

Shale.—A hard, clay-like formation having a fissile structure often shading off into slate.

Shank.—That part of a tool connecting the handle with the working part.

Shank Mortar-mixer Hoe.—See "Hoe."

Shank Street-hoe.—See "Hoe."

Shape.—Any rolled beam or bar used in a structure.

Shaper.—A machine tool for planing or finishing metal.

Shape Steel.—Same as "Shape," *q.v.*

Sharp Sand.—See "Sand."

Shay Locomotive.—See "Locomotive."

Shear.—To slide one part of a body upon an adjacent part. The stress set up in opposition to a shearing action.

Counter Shear.—A shear in opposition to another shear.

Double Shear.—A sliding on two different but parallel planes.

End Shear.—The shear at the end of a beam or girder.

Longitudinal Shear.—A shear parallel to the longitudinal axis of a member.

Negative Shear.—A relative term usually applied to a shear producing a downward motion.

Positive Shear.—A relative term usually applied to a shear producing an upward motion.

Residual Shear.—A permanent shear deformation.

Single Shear.—A sliding, or a tendency to slide, on one plane.

Transverse Shear.—A shearing action parallel to the transverse axis of a body.

Shear Diagram.—See "Diagram."

Sheared Edge.—An edge of a plate which has been cut in a shearing machine.

Sheared Plate.—See "Plate."

Shearing Machine.—A machine for shearing metal, consisting of a movable jaw-cutter operating against a fixed cutting edge.

Shearing Modulus of Elasticity.—See "Elasticity."

Shearing Strain.—See "Strain."

Shearing Strength.—See "Strength."

Shearing Stress.—See "Stress."

Shears.—Same as "Shearing Machine," *q.v.*

Angle Shears.—A shearing machine especially adapted for cutting angles.

Hoisting Shears, or Sheers.—A support made of two timbers which cross each other near one end and are pivoted so that they may be spread more or less. Used in hoisting gin poles.

Shear Steel.—See "Steel."

Sheathing.—A covering or casing of planks. Used on caissons, cribs, and the like.

Sheave.—A wheel with a grooved face for carrying a rope or cable.

Derrick Sheaves.—The stationary sheaves in the mast and boom of a derrick.

Head Sheaves.—The sheaves mounted on the head block of a pile-driver.

Snatch-block Sheave.—The grooved wheel in a snatch-block.

Sheave-stand.—A frame or support for a sheave and its bearings.

Sheep-shank.—See "Knot."

Sheet-bend.—See "Knot."

Sheet-bend with a Toggle.—See "Knot."

Sheeting.—Same as "Sheathing," *q.v.*

Sheet Iron.—See "Iron."

Sheet Lead.—See "Lead."

Sheet Packing.—See "Packing."

Sheet Piles.—See "Pile."

Sheet Piling.—See "Piling."
Shelf.—A flat projection from a wall or column.
Shelf Angle.—Same as a "Seat Angle." See "Angle."
Shell.—A hollow cylinder for piers. A casing. A framework not filled in.
Shellac.—A gum made from a resinous exudation of an East Indian scale insect. When mixed with alcohol it forms a varnish which is much used in the arts and is termed "Shellac."
Shield.—A bulkhead or contrivance to protect workmen and property, used in certain classes of underground work.
Shift.—A relay or change of workmen.
Shift-boss.—The foreman of a shift.
Shim.—A small piece of wood or metal placed between two parts or members of a structure to bring them to a desired relative position.
Shim-bolt.—A bolt used to fasten a shim in place.
Shimming Plate.—See "Plate."
Shingle.—A thin, wedge-shaped piece of wood used for roof covering, laid overlapping each other. A steel plate employed in making a splice. To make a compound splice by cutting the component parts at different places.
Shingle Splice.—See "Splice."
Ship Auger.—See "Auger."
Shipping.—A general term applied to vessels collectively. The act of despatching goods.
Shipping-bill.—A list of the articles shipped.
Shipping Invoice.—See "Invoice."
Shipping-list.—A list of all the articles to be shipped.
Shipping-weight.—The weight of the articles shipped, including that of the wrappings and packing.
Shock.—A jar; the effect of a blow; the sudden absorption of energy.
Shoe.—That part or detail of a span which transfers the load from the end pin to the bearing plate or to the intervening rollers. Also a cast-iron point used on piles when driving them through hard ground.
Pile Shoe.—A conical iron point with projecting prongs, by means of which it is fastened to the end of the pile before driving.
Shoe Block.—See "Block."
Shoe Pin.—See "Pin."
Shoe Plate.—See "Plate."
Shoot.—Same as "Chute," *q.v.*
Shop.—The place where bridge spans are fabricated.
Machine Shop.—A shop for metal turning, planing, and drilling.
Pattern Shop.—A wood-working shop in which patterns are made.
Shop Drawing.—See "Drawing."
Shop Rivet.—See "Rivet."
Shore.—The land adjacent to a body of water. A support or a prop. To support with a shore.
Shore Span.—See "Span."
Shoring.—A general term covering a system of shores or props.
Short Column.—See "Column."
Short-leaf Yellow Pine.—See "Pine."
Short Ton.—See "Ton."
Shot.—Small lead balls, used for gradually applying a load in a certain style of testing machines. An explosion in blasting.
Shoulder.—The bearing surface perpendicular to a member produced by a projection on or a recess in such member.
Shoulder Block.—See "Block."
Shove Joint.—See "Joint."

Shrink.—To draw together; to contract. To attach one piece to another by heating it, placing it, and then allowing it to cool.

Shrink Rule.—See "Rule."

Shrouded Pinion.—See "Pinion."

Shut.—A seam or opening in metal formed during manufacture.

Cold Shut.—The freezing over of the top surface of an ingot before the mould has been filled, due to an interruption of the stream of molten metal.

Side Bracing.—See "Bracing."

Side Track.—See "Track."

Sidewalk.—A walk for pedestrians at the side of the roadway of a bridge.

Siding.—Same as "Side Track," *q.v.*

Siemen's Process.—A process for making steel by using a regenerative gas furnace which utilizes the heat of the escaping gases in reheating firebricks placed in the passageways for air and gas leading to the furnace. Two sets of passageways are required, being u ed alternately. While one is conveying the gas and air to the metal, the other is being reheated by the escaping gas from the hearth. Every twenty or thirty minutes a valve is moved, so as to alternate the flow.

Siemen's-Martin Process.—The acid open-hearth process of making steel. See "Steel."

Sieve.—An apparatus consisting of wires strung on a frame or box, so as to form a net-work of meshes through which a granular material is sifted.

Gravel Sieve.—A coarse-meshed sieve for sifting gravel.

Sand Sieve.—A sieve with meshes less than a tenth of an inch in size, used for sifting sand.

Standard Sieve.—A term applied to sieves used in cement testing, one size having one hundred meshes per lineal inch and the other two hundred meshes per lineal inch.

Silica.—A dioxide of silicon (SiO_2). It occurs in nature as quartz.

Silicate of Lime.—See "Lime."

Bicalcic Silicate.—A union of calcium and silica ($2CaO.SiO_2$).

Silicious.—Having the nature of silica or pertaining thereto.

Silicon.—A chemical element of the non-metallic order.

Silky Fracture.—See "Fracture."

Sill.—The lower horizontal member of a framed bent.

Bank Sill.—A sill placed on the end of an embankment to support the stringers of a wooden trestle.

Cap Sill.—A sill placed on piles.

Intermediate Sill.—A horizontal member in the plane of a timber trestle bent between the elevations of cap and sill, to which the posts are framed.

Mud Sill, or Sub Sill.—A sill placed on short cross blocks resting on the earth, to support a framed bent.

Silt.—A fine, earthy sediment deposited by muddy water.

Simple Beam.—See "Beam."

Simple Curve.—See "Curve."

Simple Knot.—See "Knot."

Simple Span.—See "Span."

Simplex Pile.—See "Pile."

Sine Curve.—See "Curve."

Single-acting Pump.—See "Pump."

Single Block.—See "Block."

Single Cancellation.—See "Cancellation."

Single Concentration.—See "Concentration."

Single Intersection.—Same as "Single Cancellation." See "Cancellation."

Single Intersection Truss.—See "Truss."

Single Lacing.—See "Lacing."

Single Latticing.—See "Latticing."
Single Lip Screw Auger.—See "Auger."
Single Locomotive Excess Load.—See "Locomotive Excess Load."
Single Punch.—See "Punch."
Single Riveting.—See "Riveting."
Single Shear.—See "Shear."
Single Shear Steel.—Same as "Shear Steel," *q.v.*
Single Track.—See "Track."
Sinking.—The process of lowering cribs, caissons, and piers to their foundations.
Sinking Fund.—A fund built up during a period of time to provide a given sum of money at the end of that period, by making at regular intervals uniform deposits which draw compound interest.
Siphon.—A bent tube or pipe having unequal legs, employed for drawing off water when the summit of the bend is higher than the supply, and the discharge end (the longer leg) is lower than the supply.
Steam Siphon.—A siphon in which a partial vacuum is made and maintained by the condensation of steam.
Siphon Condenser.—See "Condenser."
Siphon Culvert.—Same as "Siphon," *q.v.*
Sisal Hemp.—See "Hemp."
Sisal Rope.—See "Rope."
Sister Block.—See "Block."
Sister Hook.—See "Hook."
Skeleton-construction.—A framework of structural steel which sustains all the external loads or forces from the top of a building to the foundation.
Skeleton Diagram.—See "Diagram."
Skeleton Drawing.—Same as "Skeleton Diagram," *q.v.*
Skelp.—A strip of iron or steel prepared for making pipes and tubes.
Skew.—Making an oblique angle.
Skew Arch.—Same as "Oblique Arch." See "Arch."
Skewback.—The beveled stone, iron plate, or course of masonry which supports the foot of an arch ring. Also the casting on the end of a trussed girder to which the tension rod is attached.
Skew Bridge.—See "Bridge."
Skew Crossing.—Same as "Oblique Crossing." See "Crossing."
Skew Portal.—See "Portal."
Skew Span.—See "Span."
Skid.—To slip or slide without revolving.
Skid Girder.—See "Girder."
Skids.—Timbers used as a track in sliding heavy objects.
Skid-way.—A frame or form used for skidding heavy articles.
Skim-coat.—A finishing coat of plaster used to give a smooth surface to a rough wall of concrete.
Skimming Plate.—See "Plate."
Skin.—A thin coating formed during the cooling of cast metals.
Skin Friction.—See "Friction."
Skinned Bolt.—See "Bolt."
Slab.—A flat, relatively thin, mass of wood, stone, concrete, or metal.
Bending Slab.—A plate of metal with holes punched in it for holding pins around which thin plates or bars may be bent to required shape.
Slabbed Tie.—See "Tie."
Slab Tie.—See "Tie."
Slack.—Not tightened; that portion required to be taken up to make a structure rigid. To loosen.

Slag.—Cinder. The molten substance, other than the metal under treatment, consisting of acid or basic oxides which may be composed of the gangue of the ore combined with a flux (usually lime) in smelting operations; or of substances (usually lime and iron oxide) introduced for the purpose of effecting or assisting in the purification process.

Slag Cement.—See "Cement."

Slag Concrete.—See "Concrete."

Slag Sand.—Slag ground to the consistency of sand and used to replace the sand in mortar or concrete.

Slake.—To become disintegrated by the action of water or moisture.

Slaked Lime.—See "Lime."

Slaking.—The action of the air or water in producing disintegration.

Air Slaking.—Decomposition of any material exposed to the air, such as lime.

Slapped Cement.—See "Cement."

Sledge.—A heavy hand hammer having a long handle for use by both hands.

Sledge Hammer.—See "Hammer."

Sleeper.—A railroad cross tie of wood, concrete, or metal, used to support and fix the rails of a railroad track. Generally called a "Tie."

Sleeve.—A hollow cylinder or tube, used to connect round bars, bolts, shafting, etc.

Handle Lock Sleeve.—A threaded sleeve, or elongated nut, having a handle by which it is turned and locked at some desired position.

Lock Sleeve.—A sleeve connecting two parts of shafting and arranged to lock with one of them by means of a shifting motion.

Sleeve Coupling.—See "Coupling."

Sleeve Nut.—See "Nut."

Slide, or Land Slide.—A displacement of an unstable earth bank due to gravity and saturation.

Slide Rule.—An instrument for making rapid computations mechanically, consisting of two or more sliding or revolving parts bearing graduations based on the logarithms of the numbers shown.

Duplex Slide Rule.—A slide rule of the stick type having an interior slide of the same thickness as the rule and its two faces flush with those of the exterior portions. Both rule and slide are graduated on both faces.

Manheim Slide Rule.—A slide rule of the stick type graduated on one face only. The slide has one face only flush with the rule though graduated on both faces; being thinner than the rule, it has to be reversed when using the lower face.

Spiral Slide Rule.—A slide rule of the revolving type. It consists of a hollow sleeve having graduations and being capable of sliding along and revolving around a continuous cylinder which is held stationary by a handle. The scale on the sleeve is arranged in the form of a spiral, hence the name.

Thacher Slide Rule.—A slide rule of the revolving type having an exterior frame of twenty graduated bars attached to rings at their ends. The slide is an interior cylinder and is capable of both rotation and sliding inside the bars. The exterior frame of bars is also capable of rotation. A most valuable instrument in any bridge engineer's office.

Slide Valve.—See "Valve."

Sliding Bearing.—See "Bearing."

Sliding-ends.—The ends of a bridge resting on a sliding bearing.

Sliding Friction.—See "Friction.'

Sliding Pulley.—See "Pulley."

Sling.—A closed loop of wire, chain, or rope for convenient passing under a body and attaching to the hook of a derrick tackle for the purpose of hoisting.

Rope Sling.—A sling made of rope.

Sling Dog.—See "Dog."

Slip.—An earth slide. A long, narrow water space between two wharves or piers.

Land Slip.—Same as "Land Slide," *q.v.*

Slip Joint.—See "Joint."

Slogging Chisel.—See "Chisel."

Slogging Hammer.—See "Hammer."

Slop Brick.—See "Brick."

Slope.—The inclined face of a cutting or of an embankment.

Slope Stake.—See "Stake."

Slope Wall.—See "Wall."

Slot.—An oblong hole cut through a piece of metal, plank, etc. A groove cut in an axle or shaft to receive the key of a pulley or gear.

Slotted Eye.—See "Eye."

Slotting.—The act of cutting a slot.

Slotting-machine.—A machine for cutting slots.

Slot Washer.—See "Washer."

Slow-setting Cement.—See "Cement."

Sluice.—An artificial channel for conducting water. To wash away earth or gravel by means of a swift stream of water.

Slumy.—Consisting of light gravel and silt.

Small Ashlar.—See "Ashlar."

Small Ashlar Masonry.—See "Masonry."

Smelt.—To extract the metals from an ore by heating in a reduction furnace, usually by means of coal, coke, or charcoal.

Smith's (C. Shaler) Formula.—A formula for long timber columns, viz.:

$$p = \frac{5000}{1 + \frac{1}{250} \cdot \frac{l^2}{d^2}}$$

where p = ultimate compressive resistance in pounds per square inch.
l = length of column in inches.
d = least side of column section in inches.

Smooth Dressing.—See "Dressing."

Smooth Fracture.—See "Fracture."

Snag.—A tree, or portion thereof, having one end resting on the bed of a river or lake and the other end at or near the surface of the water.

Snake.—To drag or haul, especially by a chain or rope fastened to one end of an object such as a log. A defect in rolled metal.

Snap.—A tool used in field riveting to form the head of the rivet. It consists of a hammer-like head on a handle and having one of its faces hollowed out to give the desired shape to the rivet head. By placing this on the hot metal and striking it with a sledge, the rivet end is forced to conform to the shape of the hollow. Also a spring catch as in a snap-hook. To break suddenly with a short fracture.

Rivet Snap.—A tool used for forming the head of a rivet. See "Snap."

Snap-head Rivet.—See "Rivet."

Snap Link.—See "Link."

Snatch Block.—See "Block."

Snatch Block Sheave.—See "Sheave."

Snipping.—Chipping off, as with a tool struck by a hammer. Cutting off quickly with a pair of snips.

Snips.—Small, stout hand shears used for cutting sheet metal.

Snub.—To check suddenly as in the case of a swiftly moving rope by taking a turn around a post or tree.

Snubbing Line.—See "Line."

Snubbing Post.—See "Post."

Soaking Pit.—A pit in which steel ingots are placed immediately after casting, so that the mass of the ingot may acquire a uniform temperature before rolling.

Soapstone.—A variety of steatite, *q.v.*

Socket.—A cavity or an opening specially adapted to receive and hold some correspondingly shaped piece. Also the metal piece having a socket for the reception of a tool or shank of some tool.

Socket Drill.—See "Drill."

Socket Mortar Hoe.—See "Hoe."

Socket Wrench.—See "Wrench."

Soffit.—The lower surface of an arch.

Soft Steel.—See "Steel."

Soft Wood.—See "Wood."

Solder.—A compound of different metals of low fusing temperatures which when melted is used to unite pieces of other and harder metals such as copper, brass, or sheet tin.

Soldering Iron.—A tool with a pointed or wedge-shaped bit, made of copper, having an iron shank and a wooden handle, used for applying solder while hot.

Soldering Pot.—A small, portable furnace having a clamp to hold wires that are to be soldered together and a pot to hold the melted solder. Used by linemen.

Solder Joint.—See "Joint."

Solenoid.—An electrical conductor wound in the form of a helix with a straight axis.

When carrying an electric current it acts as a bar magnet.

Solenoid Brake.—See "Brake."

Sole Plate.—See "Plate."

Solid Arch.—See "Arch."

Solid Steel Floor.—See "Floor."

Solid Web.—See "Web."

Solitary Bent.—See "Bent."

Solvent.—A fluid, such as water or alcohol, capable of dissolving substances.

Sounding.—Measuring the depth of water. Also measuring the depth, below the ground surface, of bed rock or other strata.

Sounding Rod.—See "Rod."

Sound Knot.—See "Knot."

Soundness of Cement.—See "Cement."

Spacer.—An iron casting usually spool-shaped with a hole through its axis, used to separate beams or girders when two or more of them are used to form a member.

Spacing Punch.—See "Punch."

Spacing-table.—A movable table with a gauge on one side, used in shops for multiple punching work.

Spacing Washer.—Same as "Packing Washer." See "Washer."

Spade (in concreting).—To work the mortar to the face of the concrete by running a spade up and down next to the form. A digging tool.

Spall or Spawl.—A small piece of stone chipped from a larger one.

Spalling Hammer.—See "Hammer."

Span.—The distance between two supports holding up a structure. The structure itself that rests on the supports, as a span of a bridge. To reach from one support to another by means of a structure.

Anchor Span.—In a bridge consisting of a series of cantilevers, the span that separates two cantilever arms of other spans is termed an "anchor span."

Bascule Span.—The moving span of a bascule bridge, *q.v.*

Beam Span.—A span built with beams.

Span.

Cantilever Span.—That span of a cantilever bridge, which contains a suspended span and either one or two cantilever arms. In some cases the suspended span (most improperly) is omitted, making the cantilever span consist of two cantilever arms only.

Channel Span.—The span which bridges the deepest part of a river or that part most accessible for navigation.

Clear Span.—The distances between the two inside faces of the supports of a span.

Continuous Span.—A span that is supported on more than two piers or on more than one abutment and one pier and which distributes the load to the various supports on which it rests, or a series of consecutive spans effectively connected together over the points of support.

Deck Span.—One of the spans of a "Deck Bridge," *q.v.*

Draw Span.—A movable span in a bridge over a navigable stream, to permit the passage of vessels.

Effective Span.—The distance from centre to centre of end pins in a bridge span, or that between centres of bearings in any structure.

Fixed Span.—A span that is not movable, in contradistinction to a draw span.

Girder Span.—A span built of girders.

Half-through Span.—A span in which the deck is placed between the upper and the lower chords and where there is no overhead bracing.

Intermediate Span.—Any one of the spans between the end spans of a bridge.

Lift Span.—A span of a bridge that is raised for the passage of vessels.

Movable Span.—Any span of a bridge that may be moved in any manner to allow passage for vessels through or under the bridge.

Shore Span.—Either the first or the last span of a bridge.

Simple Span.—A span that rests on two supports, one at each end, and that does not affect the stresses in the adjoining spans.

Skew Span.—A span making an angle, other than a right angle, with the axes of the piers and abutments.

Spread Span.—A span at the end of a bridge so spread out at the shore that diverging tracks may be run thereon.

Suspended Span.—A span connecting two cantilever arms and supported wholly thereby.

Swing Span.—A span that revolves on a centre pier or swings from an end pier to allow a passage for vessels through the bridge.

Through Span.—A span in which the traffic is carried between the trusses and which has lateral bracing in the plane of the upper chords.

Tower Span.—A span directly over and supported by a tower in a trestle or viaduct.

Truss Span.—A span supported by trusses.

Span Dog.—See "Dog."

Spandrel.—The space from abutment to abutment in an arch bridge extending from the top of the arch masonry to the top of the roadway.

Spandrel Braced.—In the form of a trussed arch, in which the top chord is horizontal and the bottom chord is arched.

Spandrel Column.—See "Column."

Spandrel Hanger.—See "Hanger."

Spandrel Wall.—See "Wall."

Spanish Windlass.—See "Windlass."

Span-length.—The distance from centre to centre of supports.

Clear Span Length.—Same as "Clear Span." See "Span."

Effective Span Length.—Same as "Effective Span." See "Span."

Spanner.—A wrench for coupling and uncoupling hose.

Sparry.—Pertaining to the carbonate of iron.

Spathose.—Having an even lamellar or flatly foliated structure.

Spatula.—A broad, flat, paddle-shaped blade of wood or metal used for smoothing, scooping up, and stirring soft materials.

Spear-heat Bit.—A bit having a spear-shaped end.

Specifications.—That part of a contract describing the details of construction and giving directions, restrictions, etc.

Specific Gravity.—See "Gravity."

Specimen Test.—See "Test."

Specular.—Having a lustrous appearance, a term descriptive of a variety of hematite and also a variety of pig iron.

Spelter.—Crude zinc before refining.

Spider.—A low tripod; the internal frame or skeleton of a gear wheel on which a cog-wheel may be bolted, shrunken, or cast. The group of rods connecting the conical rollers to the central casting in a rim-bearing swing span.

Spider-rod.—Same as "Radial Rod." See "Rod."

Spiegeleisen.—Pig iron that contains from ten to thirty per cent of manganese.

Spike.—A large nail or pin generally made of iron; to fasten with spikes or large nails.

Barge Spike.—A long, slim, square spike with a flat, rounded head.

Boat Spike.—A square, chisel-pointed spike with a rounded head, ordinarily from eight to ten inches long, used to fasten heavy planks in wooden floors, railroad crossings, etc.

Button-head Spike.—Similar to "Barge Spike," *q.v.*

Cut Spike.—A spike cut or stamped out of a sheet of metal.

Floor Spike.—Any spike used in putting on flooring.

Hand Spike.—A wooden lever for turning a capstan or windlass.

Jag Spike.—Same as "Jag Bolt." See "Bolt."

Marline Spike.—A tapering, sharp-pointed, iron pin used in separating the strands of a rope for splicing.

Nail-head Spike.—A spike having a long, slim, square shank and a flat, square head.

Railroad Spike.—Same as "Track Spike," *q.v.*

Screw Track-spike.—A large, threaded, square-headed bolt with the head spread out on the underside. These screw spikes are used in place of the ordinary track spike, especially on bridges. A hole is first bored in the tie at the right point and then the spike is screwed into place.

Spike Knot.—See "Knot."

Spike Maul.—See "Maul."

Spile.—Incorrectly used for "Pile," *q.v.*

Spindle.—A short shaft carrying a wheel. A vertical member in a hand-rail, also called "Baluster," *q.v.*

Spin Gear.—See "Gear."

Spiral.—The curved path of a moving point rotating about an axis with a varying radius.

Spiral Curve.—Same as "Easement Curve." See "Curve."

Spiral Gear.—See "Gear."

Spiral Riveted Pipe.—See "Pipe."

Spiral Slide Rule.—See "Slide Rule."

Spirit Level.—See "Level."

Splasher.—A guard placed over a wheel to prevent oil or water from being thrown on persons or neighboring objects.

Splay.—To widen or spread out as in the wing walls of many culverts.

Splice.—To unite two pieces firmly together. The parts used in making the union.

Butt Splice.—A splice formed by bringing the dressed square ends of two pieces of material together and joining them by welding or bolting or by riveting on plates or scabs.

Splice.

Cable Splice.—A joint or connection made of two ends of a cable. The weaving together of the ends of two ropes or cables.

Chord Splice.—A splice made in a chord of a truss.

Eye Splice.—A splice formed by bending back the end of a rope or cable and weaving it into the body of the rope so as to form a loop, or an eye.

Flange Splice.—A splice made in the flange of a beam or girder.

Full Splice.—A splice capable of developing the full strength of a member.

Lap Splice.—A splice made by placing one piece on top of another and fastening together with pins, nails, screws, bolts, rivets, or similar contrivances.

Partial Splice.—A splice that is capable of developing only a part of the resistance of a member.

Pile Splice.—The joining of two piles, end on end, by means of wooden scabs or iron plates bolted to them or by means of a cylindrical steel shell slipped over and bolted to the ends.

Rail Splice.—The joining of two rails by splice bars and bolts.

Shingle Splice.—In a member composed of a number of component parts, such as one with compound web plates, a shingle splice consists in cutting all of the said component parts at different but near-by locations and letting the splice plates extend over all the individual joints.

Stoppered Splice.—A short piece of rope spliced into a longer rope to form a stopper or check to prevent the rope from running out of a block.

Total Splice.—Same as "Full Splice," *q.v.*

Web Splice.—A splice joining two web plates.

Splice Bar.—See "Bar."

Spliced Pile.—See "Pile."

Splice Joint.—See "Joint."

Splice Plate.—See "Plate."

Splicing Shackle.—See "Shackle."

Spline.—A thin wooden strip or filler for inserting in cracks between planks.

Split Gear.—See "Gear."

Split Pulley.—See "Pulley."

Splits.—Short, flat strips of steel.

Split Switch.—See "Switch."

Split Tie.—See "Tie."

Spoke Wheel.—See "Wheel."

Sponge.—Metal in a porous form.

Sponginess.—The state or character of being soft, porous, or spongy.

Spool.—A short cylinder with a longitudinal hole through its centre; also a niggerhead on a hoisting engine.

Spoon.—A small bowl-shaped piece of metal with a rod for a handle used to clean out inaccessible holes such as a drill hole.

Spout.—Same as "Chute," *q.v.*

Spread.—To flatten out; to widen.

Spreader.—A tool for spreading refractory metal over a furnace bottom.

Spread Foundation.—See "Foundation."

Spreading-rate.—The rate a paint or paint material as used is brushed out to a continuous uniform film, measured by the area which a unit volume will cover.

Spread Span.—See "Span."

Spring.—An elastic body used to reduce the force of impact. To rise or move quickly. A flow of water from the ground.

Spring Balance.—See "Balance."

Spring Clips.—See "Clips."

Spring Dolly.—See "Dolly."

Springer.—The lowest course of a stone arch lying immediately on the top course of the support.

Springing Line.—See "Line."

Springing-points.—The points at the ends of the springing line of an arch.

Springing Stone.—See "Stone."

Sprocket.—One of the projections on a toothed wheel which engages a sprocket chain.

Sprocket Wheel.—See "Wheel."

Spud.—A small spade; a vertical timber used for anchoring scows.

Spudding Bar.—See "Bar."

Spur Gear.—See "Gear."

Spur Pile.—Same as "Batter Pile." See "Pile."

Spur Track.—See "Track."

Spur Wheel.—Same as "Gear," *q.v.*

Square.—A four-sided, plane, rectilinear figure having equal sides each at right angles to the two adjacent. A tool used by carpenters, draughtsmen, and others for laying out a right angle.

Square Thread.—See "Thread."

Square-threaded Screw.—See "Screw."

Squeegee.—A wooden scraper having a rubber edge. Used for smoothing off the grout in constructing brick pavements.

Stability.—The ability to resist change of position.

Moment of Stability.—The resistant moment of a structure due to its weight acting with a lever arm equal to the distance between its centre of gravity and the edge of the structure about which it tends to rotate.

Stable.—Standing firmly in place.

Stadia.—A method of measuring distances by noting the intercepts on a stadia board, made by the stadia wires in the telescope of a surveyor's transit.

Stadia Rod.—See "Rod."

Stadia-wires.—Two horizontal wires placed equidistant from the centre cross wire of the telescope of a transit.

Stage.—A platform, either fixed or swinging, used in erection of high structures; a scaffold; also the interval between two platforms used in shoveling, throwing, or lifting excavated material.

Stagger.—To arrange in a zigzag order, as the staggering of rivets.

Staggered Riveting.—See "Riveting."

Staging.—Same as "Stage," used collectively. See "Stage."

Stainer.—One who applies stain. A coloring matter.

Stake.—A short, flat-sided piece of wood sharpened at one end, used for marking out on the surface of the ground where work is to be done and what it is.

Berme Stakes.—Stakes showing the side lines of a berme.

Finishing Stakes.—Final stakes set for the completion of the work.

Grade Stakes.—Stakes showing by suitable notation the cut or fill required to reach the grade line.

Slope Stakes.—Slope stakes or toe stakes are stakes set on the sides of a proposed cut or fill in order to indicate the position of the top or the toe of the slope.

Stalk.—A spiked iron rod forming the centre for a core; one of the upright side pieces of a ladder.

Stamp.—A die; to make an impression on a surface by means of a die.

Stamping Hammer.—See "Hammer."

Stanchion.—An upright post supporting a roof.

Standard.—Any measure of extent, quantity, quality, or value established by law or by general usage.

Standard Gauge.—See "Gauge."

Standardize.—To regulate by a standard.
Standardized Tape.—See "Tape."
Standard Knot.—See "Knot."
Standard Sieve.—See "Sieve."
Standard Thread.—See "Thread."
Standing Block.—A pulley-block fixed to some permanent support.
Standing Bolt.—Same as a "Stud Bolt." See "Bolt."
Standing-end.—As applied to a rope, it is the end made fast to a block or other fixed point.
Standing Pile.—See "Pile."
Standing Rope.—See "Rope."
Staple.—A standard; a piece of wire or metal bent into the shape of the letter U, and having its ends sharpened to a point so as readily to penetrate wood.
Starling.—A cutwater; the projecting end of a bridge-pier, usually so shaped as to allow ice, drift, etc., to strike it without injury.
Starling Coping.—Same as "Cocked-hat," *q.v.*
Starred Angles.—See "Angle."
Star Section.—See "Section."
Star Strut.—See "Strut."
Static.—Pertaining to or designating bodies at rest or forces in equilibrium.
Static Deflection.—See "Deflection."
Static Equilibrium.—See "Equilibrium."
Static Load.—See "Load."
Statics.—That branch of mechanics which deals with a balanced system of forces acting on bodies at rest.
Graphic Statics.—A method of resolving and combining forces, determining their resultant, its direction and point of application, shears, and bending moments by graphical processes.
Static Stress.—See "Stress."
Stationary Engine.—See "Engine."
Stave.—One of the boards joined laterally to form a barrel or hollow cylinder. Pieces of wrought iron welded together as a basis for making shafts. To swell up the end of a tube.
Stay.—A rope used to support a vertical pole or mast, such as a derrick mast. To support by means of stays.
Back-stay.—A rope or cable extending backward from the head of a mast and fastened to some permanent object. A rear cable in a suspension bridge running from the top of tower to the anchorage.
Stay Bolt.—See "Bolt."
Stayed-link Chain.—See "Chain."
Stay Plate.—Same as "Batten Plate." See "Plate."
Stay Pile.—See "Pile."
Stay Rod.—See "Rod."
Stay Wire.—Same as "Guy Wire," *q.v.*
Steamboat Jack.—See "Jack."
Steamboat Ratchet.—See "Ratchet."
Steam-chest.—The chamber, adjoining the cylinder of a steam engine, in which the slide valve works.
Steam Condenser.—See "Condenser."
Steam Crane.—See "Crane."
Steam-cylinder.—A cylinder in which steam does work by expanding against a movable piston.
Steam Dredge.—See "Dredge."
Steam Engine.—See "Engine."

Steam Gauge.—See "Gauge."
Steam Hammer.—See "Hammer."
Steam Hammer Pile Driver.—See "Pile Driver."
Steam Hoist.—See "Hoist."
Steam Hose.—See "Hose."
Steam Jacket.—See "Jacket."
Steam Jet.—See "Jet."
Steam Port.—See "Port."
Steam Riveter.—See "Riveter."
Steam Siphon.—See "Siphon."
Steatite.—Massive talc or soapstone, a hydrous magnesian silicate.
Steel.—A modified form of iron, not occurring in nature, made from pig iron by oxidizing most of the carbon.

Acid Steel.—Steel made without the use of lime.

Acid Bessemer Steel.—A metal produced by the decarburization of crude pig iron in a converter where finely divided air currents are blown through the molten mass. The lining of the converter is of a silicious material that will have no effect on the phosphorus, hence that element is not eliminated.

Acid Open-hearth Steel.—A metal formed of pig iron, cast iron, and wrought iron or steel scrap, which is converted into steel by the direct action of an oxidizing flame in a regenerative gas furnace. The furnace is lined with a silicious material that has no effect on the phosphorus content.

Alloy Steel.—A steel carrying a certain portion of some other metal, such as nickel or vanadium.

Basic Open-hearth Steel.—A metal formed of pig iron, cast iron, and wrought iron or steel scrap, which is converted into steel in a furnace having a lining of dolomitic limestone in order to resist the action of the slag. This slag contains much of the phosphorus in combination with calcined lime with which the furnace is charged. In this way the phosphorus content is reduced materially.

Bessemer Steel.—Steel made by the "Bessemer Process," *q.v.*

Blister Steel.—Steel made from wrought iron by heating it while in contact with some form of carbon.

Boiler Steel.—A medium steel rolled into plates from one-fourth to one-half inch in thickness and used for making boilers.

Bronze Steel.—An alloy of copper, tin, and iron used as gun metal.

Burning Steel.—A mechanical separation of the grains due to extreme overheating of steel.

Burnt Steel.—Steel that has been overheated in the making or remelting. It is coarse-grained and very brittle when either hot or cold.

Carbon Steel.—Ordinary steel which contains no other alloying element than the usual amount of manganese. The term is generally employed in contradistinction to nickel steel or other alloy steel.

Case-hardened Steel.—Steel with the outer skin hardened by heating, after being made into shape, with some such animal substance as grease, bone, hoofs, or horns.

Case Steel.—The outside skin on steel caused by case hardening.

Cast Steel.—Steel that is cast into shape directly from the furnace instead of being cast into ingots and rolled or melted.

Cemented Steel.—Steel produced by impregnating bars of wrought iron or soft steel with carbon at a temperature below the melting point.

Charcoal Steel.—Steel in which charcoal is used for a fuel in its production.

Chrome Steel.—Steel that usually contains two per cent of chromium and from eight-tenths of one per cent to two per cent of carbon. It is very hard and has a high elastic limit.

Steel.

Cold-short Steel.—A steel that is very brittle when cold, usually due to an excess of phosphorus.

Converted Steel.—Steel that has undergone a process of cementation in fire brick chambers or converting pots.

Crucible Cast Steel, or **Crucible Steel.**—Steel made by melting down in a closed crucible the various grades of iron or steel with or without the addition of carbon, ore, or other materials.

Double Shear Steel.—Steel made by a process in which the shearing and welding described for single shear steel is repeated.

Fiery Steel.—Burnt steel showing very coarse, bright grains when fractured.

Gad Steel.—Flemish steel wrought from wedge-shaped ingots.

German Steel.—Steel made in Germany—an obsolete term.

Hardening of Steel.—Bringing the metal to the condition in which it is best able to resist abrasion or scratching. This is accomplished by heating the steel to a high temperature and cooling quickly, or by mechanical working.

Hard Steel.—Steel that has undergone the process of hardening. Also same as "High Steel," *q.v.*

Hay Steel.—Steel made by a process patented by a Mr. Hay. It was used in the construction of the bridge over the Missouri River at Glasgow, Mo. It is no longer manufactured.

High Steel.—Steel containing a comparatively large amount of carbon, from one-half to one per cent.

Homogeneous Steel.—A steel solid and free from blow holes. A variety of crucible steel easily bent and worked.

Hot-short Steel.—A steel that is very brittle when hot—usually due to an excessive amount of sulphur.

Ingot Steel.—Steel run from the furnace into rectangular moulds to be subsequently rolled or forged.

Low Steel.—A soft steel containing a small amount of carbon—less than one-fourth of one per cent.

Manganese Steel.—Steel containing from eleven per cent to fourteen per cent of manganese and one and one-half per cent of carbon. This is a very hard, brittle steel and has to be treated by cooling in water to remove the extreme brittleness. Used where high resistance to abrasion is necessary. Mayarí Steel, see page 68.

Medium Steel.—Steel neither very hard nor very soft, containing from one-fourth to one-half per cent of carbon.

Mild Steel.—A soft steel. Same as "Low Steel," *q.v.*

Mushet Steel.—A steel containing one and one-half per cent of carbon and from five to eight per cent of tungsten, which when hardened by air cooling holds its temper until it becomes red-hot.

Nickel Steel.—Steel containing from three per cent to five per cent of nickel and from two-tenths to one-half per cent of carbon. The addition of the nickel increases the strength and the elastic limit of the metal.

Open-hearth Steel.—Steel produced in a regenerative, reverberatory furnace where the hearth is open and exposed to the action of the flame.

Pipe in Steel.—A defect in the top of an ingot due to the shrinking of metal while cooling, thus leaving a cavity.

Puddle Steel.—A steel made by the puddling process in a reverberatory furnace in which the carbon is reduced at a low temperature to one-half of one per cent. This process is seldom used nowadays.

Restoring Steel.—Treating burnt steel by heating and mechanically working the metal.

Rivet Steel.—A soft steel from which rivets are made.

Steel.

Rolled Steel.—Steel that has been cast into ingots and then passed through a succession of rolls until the desired final shape is obtained.

Self-hardening Steel.—Same as "Mushet Steel," *q.v.*

Shape Steel.—Same as "Shape," *q.v.*

Shear Steel.—Steel made in the form of bars from blister steel by shearing the latter into short lengths, piling these upon each other and heating, and welding them by rolling or hammering into one piece.

Soft Steel.—Same as "Low Steel," or "Mild Steel," *q.v.*

Tempered Steel.—Steel that has undergone the tempering process.

Temper of Steel.—Degree of hardness produced in high carbon steel by water or oil treatment of cooling. See "Temper" and "Tempering."

Tool Steel.—Steel which, by special treatment or peculiar composition with alloying metals, is adapted to retain a cutting edge at comparatively high temperatures so as to permit of high cutting speeds. Messrs. Taylor and White give the following as the best composition for such steel. Vanadium, 0.29 per cent; tungsten, 18.19 per cent; chromium, 5.47 per cent; carbon, 0.674 per cent; manganese, 0.11 per cent; and silicon, 0.043 per cent.

Tungsten Steel.—Steel usually containing from five to ten per cent of tungsten (sometimes as much as twenty-four per cent) and from four-tenths to two per cent of carbon.

Vanadium Steel.—An alloy steel containing a small percentage of vanadium which has the effect of raising the elastic limit and ultimate strength of the metal, mainly by purification.

Weld Steel.—Steel capable of being welded.

Wild Steel.—Steel that spits and flies in the ladle, usually caused by overoxidization of the metal.

Steel Joist.—See "Joist."

Steel Pile.—See "Pile."

Steel Press.—See "Press."

Steining.—The brick or stone wall lining a vault.

Stem.—The handle of a tool; the projecting rod of a slide valve; a narrow portion of an object connecting two larger portions. To hold back, to resist.

Stem-section.—That portion of an object containing the stem.

Stepped.—Formed into a series of steps.

Stepped Gear.—See "Gear."

Step Stone.—See "Stone."

Stereotomy.—The science of cutting solids into certain shapes. Generally applied to stonework.

Sterro Metal.—See "Metal."

Stevedores' Knot.—See "Knot."

Stiff.—Rigid, not easily bent, not working easily.

Stiffener.—A secondary member, usually an angle, attached to a plate to prevent buckling.

End Stiffener.—Vertical angles riveted to the web of a plate girder at its ends for the purpose of stiffening it and transferring the end shear to the shoe or base plate.

Intermediate Stiffener.—Any one of the stiffeners on a plate girder between the end stiffeners.

Web Stiffener.—An angle riveted to the web of a beam to distribute a load or to prevent buckling.

Stiffening Angles.—See "Angle."

Stiffening Girder.—See "Girder."

Stiffening Rib.—See "Rib."

Stiffening Strut.—See "Strut."

Stiffening Truss.—See "Truss."
Stiff Leg.—See "Leg."
Stiff-leg Derrick.—See "Derrick."
Stirrup.—In reinforced concrete beams or slabs, a U-shaped bar inserted for the purpose of resisting diagonal tension, or so-called shear.
Stitch Rivet.—See "Rivet."
Stock.—The raw material used for charging a furnace. The foundation for the anvil of a power hammer. An apparatus or tool for holding another tool.
Die Stock.—The frame, with handles attached, used for holding and turning the dies which cut the threads on rods or pipes.
Drill Stock.—The holder which receives the shank of a drill.
Screw Stock.—Same as "Die Stock," *q.v.*
Stock Ramming.—A process for stopping leaks in a cofferdam by ramming clay through a hole cut in the supporting timbers.
Stone.—A small piece of rock. A piece of rock hewn or shaped for specific use.
Arch Stone.—Same as "Voussoir," *q.v.*
Axed Stone.—Stone roughly dressed with a heavy, axe-like tool.
Bed Stone.—One of the stones in a bottom course of masonry.
Bridge Stone.—A flat stone bridging a gutter or other small opening.
Broken Stone.—A term applied to rock which is crushed or broken into small pieces and used for concrete, road pavement, ballast for tracks, etc.
Cement Stone.—Any rock having the necessary alumina, silica, and lime content which can be converted into cement under proper treatment.
Cut Stone.—Stone which has been dressed with a mason's chisel to a smooth surface.
Dimension Stone.—Large cut stone having the face left rough, used in massive masonry.
Dorchester Sandstone.—A sandstone found in Dorchester, New Brunswick.
Drafted Stone.—Stone having a narrow chisel-draft cut around the face or margin.
Drip Stone.—A moulding or cornice projecting from a column to prevent rain water from trickling down.
Iron Stone.—An oxide of iron rendered impure through the admixture of silica and clay.
Keystone.—The centre or highest voussoir or arch stone.
Masonry Stone.—Stone employed in masonry construction.
One-man Stone.—A rough classification for stone of a size that can be lifted and placed by one man.
Ring Stone.—Same as "Voussoir," *q.v.*
Rubbed Stone.—Same as "Rubbed Dressing," *q.v.*
Sandstone.—A rock formed by the consolidation of sand.
Springing Stone.—The first course of stone below the springing line in an arch.
Step Stone.—The stone which forms a step in foundations.
Stone Axe.—See "Axe."
Stone Boat.—A boat or barge which carries stones.
Stone-breaker.—A machine for crushing stones.
Stone Bridge.—See "Bridge."
Stone Cutter.—See "Cutter."
Stone Drill.—See "Drill."
Stone Girder.—See "Girder."
Stone Hammer.—See "Hammer."
Stone Planer.—A machine for smoothing the surface of a flat stone.
Stone-polisher.—Either a machine or a man that polishes the face of a stone, after it has been smoothed, by the use of powdered pumice-stone and water.
Stone-ring.—Same as "Belt Course," *q.v.*
Stone Saw.—See "Saw."

Stop-cock.—Same as "Cock," *q.v.*
Stoppered Splice.—See "Splice."
Stop Valve.—Same as "Gate Valve," *q.v.*
Stop-water.—A plug of soft wood driven tightly into a hole at the joint of a scarf which when wet swells and prevents leakage through the said joint.
Storm Cable.—See "Cable."
Stove Bolt.—See "Bolt."
Straight Abutment.—See "Abutment."
Straight Dolly.—See "Dolly."
Straight-edge.—A thin bar of wood or steel used by draughtsmen for drawing straight lines. Also a bar or narrow board having at least one straight edge, used on construction work to obtain a flat and level surface.
Straightening-machine.—A machine used for straightening bars, beams, channels, etc.
Straightening Rolls.—See "Rolls."
Straight Line.—See "Line."
Straight-line Formula.—See "Formula."
Straight-link Chain.—See "Chain."
Straight-shank Drill.—See "Drill."
Strain.—The deformation caused by an external force applied to any piece of material or to any bridge member. Often loosely used for stress.
Angular Strain.—Same as "Torsional Strain," *q.v.*
Compressive Strain.—The deformation caused by a compression load. Also called "Shortening."
Crushing Strain.—An incorrect but rather common expression for the ultimate strength in compression. See "Ultimate Strength."
Lateral Strain.—A deformation at right angles to the axis of the member.
Rate of Strain.—The ratio of the deformation to the original length of a member.
Shearing Strain.—The deformation produced by a shearing force.
Tensile Strain.—The deformation produced by an external tensile force. Also called "Stretch" or "Elongation."
Torsional Strain.—A deformation in a member caused by a twisting moment.
Transverse Strain.—A deformation caused by a force acting at right angles to the axis of a member.
Strainer.—Any device used to separate small solid particles from a liquid, such as a strainer on the end of a suction hose of a pump.
Strain Sheet.—Wrongly used for "Stress Sheet," *q.v.*
Strake.—A breadth of planking; the hoop or tire of a wheel.
Strength.—The capacity to resist distortion or disintegration.
Compressive Strength.—The capacity to resist compression.
Crushing Strength.—The ultimate power of a material to resist disintegration by crushing.
Hydraulic Strength.—The strength developed by cement, mortar, or concrete setting in water.
Proof Strength.—The greatest resistance that a body can offer to an external force without the stress exceeding the elastic limit of the material.
Shearing Strength.—The resistance which a body can offer to a shearing force.
Tensile Strength.—The resistance which a body can offer to an external tensile force.
Strand.—One of the small threads used in making rope.
Strap.—A narrow band of flexible material used to encircle and hold together various articles.
Butt Strap.—A steel attaching plate, used in timber construction, fastened to the outside of two abutting timbers.
Eccentric Strap.—The band of iron or steel which embraces the circumference of the eccentric and in which it revolves.

Strap Bolt.—Same as "Lug Bolt," *q.v.*

Strap Hinge.—See "Hinge."

Strap Joint.—See "Joint."

Strap Rail.—See "Rail."

Stratification.—A geological formation consisting of layers or bands

Stratum.—A natural or artificial bed of rock or earth.

Straw-boss.—Same as "Pusher," *q.v.*

Stress.—An internal distributed force that resists the change in shape and size of a body subjected to external forces.

Advancing Load Stress.—A stress in a member induced by a load advancing on the structure.

Allowable Unit Stress.—The allowable stress per unit of area given in the specifications.

Apparent Stress.—A term used to indicate that the stress has been determined by the principles of statics, and, therefore, ignoring the effect of the lateral deformation of the member or that of secondary stresses.

Axial Stress.—A stress, either tension or compression, acting along and in the direction of the axis.

Balanced Load Stress.—A stress in a member of a draw span induced by having both arms of the draw symmetrically loaded.

Bearing Stress.—The stress developed in a bearing by the superimposed load.

Bending Stress.—The stress produced in a member by a bending moment.

Bond Stress.—The longitudinal stress set up between the surface of a reinforcing bar and the surrounding concrete.

Breaking Stress.—The stress developed in a member at the point of rupture.

Buckling Stress.—A compressive stress so great that the elastic limit of the piece is exceeded, and, in consequence, a buckling or bulging of the material occurs.

Centre of Stress.—The point of application of the resultant of the stresses on a section.

Centrifugal Stress.—A stress due to the centrifugal reaction of a live load moving in a curve. Any stress acting in an outward direction from the centre of a body.

Centripetal Stress.—Any stress acting toward the centre of a body.

Chord Stress.—Any stress which exists in a chord of a truss.

Combined Stress, or Compound Stress.—A union of stresses such as direct stress and bending.

Compressive Stress.—A stress which resists the shortening effect of an external compressive force.

Concentrated Load Stress.—Stress induced in a member by concentrated loads on a structure.

Conjugate Stresses.—Two sets of stresses each of which acts parallel to the plane upon which the other acts.

Counter Stress.—A stress in the web member of a truss which occurs for certain positions of the live load and is the reverse of the usual stress in the member or panel.

Crippling Stress.—The stress resulting in a member at the point of crippling. The stress necessary to cripple the member.

Cumulative Stress.—A stress that piles up in a member.

Dead Load Stress.—The stress resulting from the application of a static load. Generally means the stress produced in a structure by its own weight.

Direct Stress.—A stress resulting from a direct application of the load.

Direct Wind-load Stress.—Stress due to the wind load applied directly to the lateral trusses of a span.

Ellipse of Stress.—A relation between stresses such that if a pair of principal stresses, of the same or opposite kinds, be represented by the semi-major and semi-minor axes of an ellipse, respectively, the intensity of the stress in any direction in the same plane is represented by the semi-diameter of the ellipse in that direction.

Stress.

Erection Stress.—Stress induced by loads applied during the erection of a structure.

Extreme Fibre Stress.—In members subjected to bending, the intensity of stress on the fibre (or elementary strip) farthest removed from the neutral axis.

Fibre Stress.—The stress on an elementary fibre, strip, or element of a member.

Flange Stress.—The stress developed in the flange or flanges of a member.

Impact Stress, or Impact Load Stress.—Any stress caused by the sudden application of a load over and above that which the load at rest would produce.

Inch Stress.—A stress distribution on a square inch of area; the common unit of stress in metals.

Indeterminate Stress.—A stress which cannot be determined by the principles of statics.

Indirect Stress.—A stress induced by another stress.

Indirect Wind Stress.—A stress due to a transferred wind load.

Induced Stress.—Same as "Indirect Stress," *q.v.*

Initial Stress.—Stress put on a member before the regular loads are applied. This is accomplished by making the member a trifle shorter or longer than the required normal length and then forcing it into place in the structure, or by operating a turnbuckle after erection.

Intensity of Stress.—The stress per unit of area. Also called "Unit Stress," *q.v.*

Internal Stress.—Any stress in a member.

Lateral Stress.—A stress which acts at right angles to the axis of a member through which tension or compression is produced. Sometimes employed to mean the stress in a member of a lateral system.

Live Load Stress.—Any stress caused by the application of a moving load.

Longitudinal Stress.—Stress parallel to the axis of a member.

Main Stress.—Same as "Direct Stress," *q.v.*

Maximum Stress.—The greatest stress that comes on a piece, or sometimes the greatest stress a member can have with its allowable load.

Normal Stress.—A stress which acts at right angles to a plane in the interior of a body.

Primary Stress.—Same as "Main Stress," *q.v.*

Principal Stresses.—Conjugate stresses that are at right angles to each other.

Pure Stress.—A term used for cases where only one kind of stress exists.

Range of Stress.—The limits between which the stress or stresses in a member vary as the load changes.

Repeated Stress.—A stress due to a load which is applied to and removed from a body a great number of times.

Resultant Stress.—The stress resulting from combining all the stresses that act on a piece simultaneously.

Reversal of Stress.—The changing of stress from tension to compression or vice versa.

Secondary Stress.—An indirect stress set up by the deformation of a member caused by primary stresses.

Shearing Stress.—A stress which resists any action tending to slide one part of a body past an adjacent part.

Static Stress.—Same as "Dead Load Stress," *q.v.* Stress due to a quiescent load.

Sudden Stress.—The stress resulting in a member from the sudden application of a load thereto.

Tangential Stress.—A stress which acts along a plane in the interior of a body.

Temperature Stress.—A stress due to the contraction or expansion of a body from changes in temperature.

Tensile Stress.—A stress resisting the elongation of a body.

Stress.

Torsional Stress.—The stress arising from the deformation set up by a torque or twisting moment.

Total Stress.—The sum of all the stresses at a section of a body.

Traction Stress.—A stress caused by the thrust of a braked train due to the friction of the wheels on the rails when skidding, or by the horizontal effort of the locomotive wheels against the rails.

Transferred Load Stress.—The stress in a member caused by the transferring of a load from another member.

Transverse Stress.—A stress at right angles to the axis of a member.

True Stress.—A stress as measured by the deformation as it actually occurs.

Ultimate Stress.—The greatest stress which can be produced in a body before rupture occurs.

Uniform Stress.—A stress which has a uniform intensity throughout its area of action.

Uniform Load Stress.—A stress resulting from the application of a load uniformly distributed over the structure.

Uniformly Varying Stress.—A stress, the intensity of which varies as its distance from a fixed point.

Unit Stress.—The stress per unit of area; the measure of intensity of stress.

Uplift Stress.—A stress due to an uplift action, as that from the end lifting machinery in a swing span.

Vibratory Stress.—A stress caused by vibration.

Web Stress.—Any stress in a web member of a truss.

Wind Stress.—A stress caused by the application of a wind load to the structure.

Working Stress.—The allowable stress on any piece as provided in the specifications. Carelessly used for "Working Unit Stress," *q.v.*

Working Unit Stress.—The allowable unit stress or intensity on any piece as provided in the specifications.

Stress Couple.—See "Couple."

Stress Diagram.—See "Diagram."

Stress Sheet.—Same as "Stress Diagram." See "Diagram."

Stretcher.—In masonry, a stone laid with its long dimension parallel to the wall.

Stretcher Course.—See "Course."

Strict-heart Tie.—See "Tie."

Striking.—Hitting with a hammer or sledge, as striking a drill. Removing camber blocks or arch forms.

Striking Hammer.—See "Hammer."

Striking of an Arch.—See "Arch."

Striking Wedge.—See "Wedge."

String Course.—See "Course."

Stringer.—A longitudinal member extending from panel to panel of a bridge and supporting the ties or the flooring.

Chord Stringer.—A chord length subjected to bending as well as to direct stress.

Continuous Stringer.—A stringer that extends over two or more panels.

Jack Stringer, or Outside Stringer.—A stringer placed outside the line of main stringers.

Track Stringer.—A beam or girder carrying a track.

Stringer Bolt.—See "Bolt."

Stringer Bracing.—See "Bracing."

Stringer Packing.—See "Packing."

Stringer-spacing.—The distance between the centres of stringers and their location with reference to the centre line of structure.

String Packing.—See "Packing."

String-pieces.—The sloping beams of a stairway which support the treads.

String Polygon.—Same as "Equilibrium Polygon," *q.v.*

Strip.—A narrow board. To remove the timber forms from concrete. To tear off, as to remove the threads from a bolt or the teeth from a cog.

Striped Dressing.—See "Dressing."

Stripping.—Removing forms from concrete; tearing off anything.

Stripping-bill.—A local term for a bar having a curved end, used in removing forms.

Stroked.—A form of masonry dressing, also called "Droved." See "Dressing."

Columnar Stroked.—A form of dressing in masonry. See "Dressing."

Fibrous Stroked.—A form of dressing in masonry. See "Dressing."

Structure.—A general term for anything that is built or constructed, as a bridge or a building. The arrangement and organic union of the parts in a body or object.

Granular Structure.—A granular condition of iron or steel, shown in its fracture, caused by overheating in the furnace.

Lamellar Structure.—Composed of layers or lying in layers, usually applied to rock.

Substructure.—The part of any construction which supports the superstructure.

Superstructure.—The part of a structure which receives the live load directly.

Strut.—A bridge member carrying compression.

Angle Strut.—A strut built up of angle irons.

Box Strut.—Any strut built of structural shapes having a box-like cross-section.

Channel Strut.—A strut built up of channels.

Collision Strut.—A strut placed against a point a little below the middle of the inclined end post of a bridge so that, in case of a derailment or a shifted load striking the said end post, the shock will be carried longitudinally to other members and not be taken up in bending by the said inclined end post.

Counter Strut.—A web member subject to both compression and tension.

Horizontal Strut.—A compression member lying in a horizontal position.

Inclined Strut.—A compression member placed in an inclined position.

Intermediate Strut.—An overhead strut in high bridges attached to the posts of opposite trusses and lying between the upper lateral strut and the floor. In deck bridges, if used at all, it would be between the upper and the lower lateral struts.

Laced Strut.—A strut that has lacing of small bars running diagonally on the open face or faces.

Lateral Strut.—A strut in the lateral system of a bridge.

Overhead Strut.—A strut in the overhead portion of the sway bracing of a bridge.

Pedestal Strut.—A strut connecting and bracing two pedestals.

Portal Strut.—A strut in the portal bracing of a bridge.

Radial Strut.—One of a series of struts radiating from a fixed point, as the spokes of a wheel, or the radial braces of a turntable, or a swing-span drum.

Secondary Strut.—A secondary member taking up compression.

Star Strut.—A strut formed of either two or four angles placed back to back. The two-angle form is not a satisfactory type, as it fails to develop as high an ultimate strength as might properly be anticipated.

Stiffening Strut.—A strut used to overcome a buckling tendency or to fix an intermediate point of a post or column and thus reduce the value of l over r.

Sub-strut.—A sub-diagonal carrying compression.

Sway Strut.—A strut used in sway bracing.

Timber Strut.—A strut made of timber.

Vertical Strut.—A vertical compression member.

Stub Abutment.—Same as "Straight Abutment." See "Abutment."

Stub Switch.—See "Switch."

Stud.—A short projecting pin. An upright member in a wall to which the laths are attached.

Stud Bolt.—See "Bolt."

Studding.—Same as "Stud," *q.v.*

Stud-link Chain.—See "Chain."

Stuffing Box.—See "Box."
Stump Joint.—See "Joint."
Sub-contract.—See "Contract."
Sub-contractor.—See "Contractor."
Sub-diagonal.—A secondary member connecting the mid-point of a main diagonal with an adjacent panel point.
Sub-divided Panel.—See "Panel."
Sub-divided Pratt Truss.—See "Truss."
Sub-divided Warren Truss.—See "Truss."
Sub-foreman.—See "Foreman."
Sub-grade.—See "Grade."
Sub-letting.—See "Letting."
Submerged Pier.—See "Pier."
Sub-post.—See "Post."
Sub-punch.—See "Punch."
Sub-sill.—See "Sill."
Sub-soil.—The stratum of earth lying immediately under the surface soil.
Substructure.—The piers, pedestals, and abutments of a bridge or trestle.
Sub-strut.—See "Strut."
Sub-tie.—See "Tie."
Sub-vertical.—See "Vertical."
Suction.—A drawing up of a liquid by the production of a partial vacuum in a space connected with the said fluid.
Suction Hose.—See "Hose."
Suction Pipe.—See "Pipe."
Suction Pump.—See "Pump."
Sudden Stress.—See "Stress."
Sulphur.—An elementary substance which occurs in nature, characterized by a yellow color, a brittle, crystalline structure, a resinous lustre, and strong acrid fumes given off during combustion. Used sometimes in bridgework for filling around bolts in masonry.
Sump, or Sump-hole.—A depression or hole in a pier foundation, used to collect drainage water so that it may be pumped out; also a hole under a building or in a tunnel for the same purpose.
Super-elevation.—See "Elevation."
Superintendent.—The person having complete control of a piece of work.
  Day Superintendent.—The person in complete control of work during the day.
  Night Superintendent.—The person in complete control of work during the night.
Superstructure.—That portion of a bridge or trestle lying above the piers, pedestals, and abutments.
Supplement.—An addition to anything to make it complete. To add anything for that purpose.
Supplementary.—Being in the nature of a supplement.
Supply Shaft.—See "Shaft."
Supporting Machinery.—See "Machinery."
Surbase.—A border or moulding above a base.
Surcharge.—To overcharge. The earth that lies both above and behind a retaining wall.
Surface.—The condition of a track as to vertical evenness and smoothness.
Surface Condenser.—See "Condenser."
Survey.—To determine the boundaries, extent, position, elevation, etc., of a portion of the earth's surface by means of lineal and angular measurements. The result of such a process is also termed a survey, as is also the process itself.
Surveying.—The art of making surveys.

Surveyor.—A man skilled in the art of surveying.
Surveyor's Level.—See "Level."
Suspended Floor.—See "Floor."
Suspended Span.—See "Span."
Suspender.—A hanger used to suspend a floor from a cable or from a truss or other object.
Suspender Cable.—See "Cable."
Suspension Bridge.—See "Bridge."
Stiffened Suspension Bridge.—See "Bridge."
Suspension Cable.—See "Cable."
Suspension Rod.—One of the rods attached to the cable of a suspension bridge for the purpose of supporting the floor.
Swab.—A mop used for spreading tar on the surface of a concrete deck and on the bearings for paving blocks.
Swage, or Swedge.—A die or former used for shaping pieces of metals, tools, etc. To shape with a swaging block.
Sway.—To brace laterally or longitudinally against horizontal movement.
Sway Bolt.—See "Bolt."
Sway Bracing.—See "Bracing."
Sway Strut.—See "Strut."
Sweating.—A method of fastening two metallic surfaces together by means of a very thin invisible layer of solder.
Swedge.—Same as "Swage," *q.v.*
Swedged Bolt.—See "Bolt."
Swedish Iron.—See "Iron."
Swelled Column.—A column that is larger at the middle than at the ends.
Swing Bridge.—See "Bridge."
Swinging Crane.—See "Crane."
Swinging Scaffold.—See "Scaffold."
Swing Span.—See "Span."
Swipe.—To strike or drive with great force.
Switch.—A device for changing or shifting a portion of a track so that the train will be diverted. An apparatus for turning on and off an electric current.
Automatic Switch.—A switch that is worked automatically by the passage of a car, used principally by street railways; also in vertical lift bridges.
Derailing Switch.—A switch operated by hand, by machinery, or automatically, which will derail a train of cars.
Replacing Switch.—A device used for replacing on the track the wheels of derailed cars.
Split Switch, or Point Switch.—A switch having a point on one rail which fits closely against the other rail, thus giving a continuous track effect.
Stub Switch.—A switch with the ends of the rails of the main track and switch track cut off square, the switch rails being firmly fastened to a chair and the main line rails that lead toward the switch moving with a sliding motion. These switches are used only at yards.
Switch-back.—A method or system of track construction enabling a train to climb a steep slope by zigzagging back and forth over a succession of short tracks connected with each other by switches.
Switch Bar.—See "Bar."
Switching Locomotive.—See "Locomotive."
Switch-signal.—A signal to apprise the train crew which track the switch is set for. In the daytime a swinging arm is used and at night different colored lights.
Switch-stand.—The stand on one side of a track from which a hand-thrown switch is worked.

Swivel.—A device consisting of a U-shaped bar attached to a plate having a hole in its centre through which passes the headed shank of a hook, thus permitting of an axial rotation of either part.

Swivel Bridge.—Same as "Swing Bridge." See "Bridge."

wivel Hanger.—A hanger for shafting with pivoted boxes to permit a certain amount of play and adjustment in the motion of the shaft.

Swivel Head.—The upset end of the swivel hook, enlarged to prevent it from slipping through the eye in the U-shaped half of the swivel.

Swivel Hook.—The half of the swivel that works through the washer or small circular plate fastened to the U-portion of the device and to which the rope or chain is attached.

Swivel Joint.—See "Joint."

Swivel Wrench.—See "Wrench."

Sword.—A hand tool in the shape of a small sword, used for filling with mortar the joints in masonry.

Syenite.—A rock composed of feldspar and hornblende with very little or no quartz.

Sylvester-wash.—The alternate applications of a solution of soap and one of alum to the dry surface of concrete construction so as to render the same impervious to water.

Symmetry.—A condition of equality or balance of shape, size, and position between similar parts of a figure or body about a central axis.

Axis of Symmetry.—A line about which the parts of a figure or body are symmetrically disposed.

Centre of Symmetry.—The intersection of the axes of symmetry.

Plane of Symmetry.—A plane about which the parts of a figure or a body are symmetrically disposed.

Sypher Joint.—See "Joint."

T

Table of Data.—A list of the known circumstances that affect the designing of a structure.

T-Abutment.—See "Abutment."

Tackle.—A combination of ropes and pulley-blocks used in hoisting or lowering where a multiplication of force is desired. Same as "Block and Falls."

Boom Tackle.—The tackle used for manipulating the boom of a derrick.

Differential Tackle.—See "Differential Block."

Efficiency of Tackle.—The ratio of the actual load lifted to the theoretical load (*i. e.*, the pull on the fall line multiplied by the number of parts of the rope sustaining the load.)

Fleeting Tackle.—A horizontal subsidiary tackle used in connection with the main hoisting tackle to fleet members into place.

Gin Tackle.—A system of pulleys consisting of a double and a triple block, the standing end of the fall line being made fast to the double block, which is movable.

Luff Tackle.—The tackle used to hold the boom of a derrick from swinging sideways.

Tackle Block.—See "Block."

Tackle Hook.—See "Hook."

Tag Line.—See "Line."

Tail Block.—See "Block."

Tailings.—Refuse material from the mines. Also called chats. Used for making concrete.

Tail Wall.—See "Wall."

Take-up.—A device for taking up lost motion.

Talus.—The mass of fragmentary rock or soil which accumulates at the foot of a hill, slope, or cliff as disintegration proceeds above.

Tamp.—To consolidate a material by pounding.

Tamping Bar.—See "Bar."

Tangent.—A straight line passing through two consecutive points of a curve. The straight part of a railroad track.

Tangential Stress.—See "Stress."

Tank Locomotive.—See "Locomotive."

Tap.—A tool for cutting threads in a hole.

Tap Bolt.—See "Bolt."

Tape.—A long, narrow ribbon of flexible material graduated in lineal units.

Bridge Tape.—A strong flat wire divided by clips into feet, with the two end feet divided decimally.

Chain Tape.—A thin steel ribbon graduated on one side in feet and on the other side in surveyor's links.

Metallic Tape.—A tape made of cloth, but having metallic wires interwoven to give strength and to reduce the stretching.

Standardized Tape.—A tape that has been compared with the official standard of length.

Steel Tape.—A tape made of steel. Used for accurate work.

Tape Measure.—Same as "Tape," *q.v.*

Taper.—To diminish in section regularly and gradually.

Taper File.—See "File."

Taper Shank Drill. See "Drill."

Tap Wrench.—See "Wrench."

Tar.—A thick, dark, viscous liquid obtained by the destructive distillation of substances such as wood, coal, peat, etc.

Target.—A sliding disk on a level rod, used for fixing the position of the line of sight as determined by an engineer's level.

Tarpaulin.—A heavy canvas sheet used to cover materials and to protect work temporarily.

Tarred Paper.—See "Paper."

Tassel.—Same as "Corbel," *q.v.*

Taut.—Tight; tense; not slack.

T, or Tee Beam.—See "Beam."

T-Beam Girder.—See "Girder."

Teat.—Same as "Tit," *q.v.*

Teat Drill.—See "Drill."

T-Iron.—Same as "Tee," *q.v.*

Telemeter Rod.—Same as "Stadia Rod," *q.v.*

Telescope.—That part of an engineer's transit or level used for sighting on and magnifying objects.

Telltale.—An indicator. A row of straps or ropes hung over and across a railway track so as to strike any one standing on a car-roof and warn him that the train is about to pass under or through a bridge or similar structure.

Temper.—To bring a metal, such as steel, to a proper degree of hardness. The condition of steel relative to the degree of hardness.

Temperature.—The intensity of the sensible heat of a body.

Temperature Stress.—See "Stress."

Tempered Steel.—See "Steel."

Tempering.—The act of producing a temper in steel or other metal.

Oil Tempering.—A process of plunging red-hot steel into oil to harden it. A term frequently used for oil hardening because the effect on the steel is similar to that of quenching in water and then drawing the temper by a subsequent application of a moderate heat.

Tempering.

Water Tempering.—A process of heating hardened steel to draw the temper (lower the degree of hardness) and quenching in water when the desired condition (as indicated by the color) is attained.

Tempering of Mortar.—See "Mortar."

Temper of Steel.—See "Steel."

Templet, or **Template.**—A full-sized pattern, generally made of wood and used to lay off work in bridge shops.

Templet Punch.—See "Punch."

Tenacity.—That property of a body by which it resists being pulled apart.

Tender.—The attendant at a bridge or on a part of construction work. A bid on a piece of construction work. An offer to do work for a consideration. A car attached to a locomotive for carrying a supply of fuel.

Inside Lock Tender.—The man inside the air-lock who manipulates the pressure valve and the opening of the lock doors.

Lock Tender.—The man who operates the air-lock in pneumatic sinking of bridge piers.

Outside Lock Tender.—The man outside of the air-lock who assists in operating it.

Tenon.—A projection, properly of rectangular cross-section, at the end of a piece of timber, to be inserted into a socket or mortise in another timber, so as to make a joint.

Tensile.—Pertaining to tension. The character of the force which tends to separate, in the most direct manner possible, the adjoining parts of a body.

Tensile Resistance.—See "Resistance."

Tensile Strain.—See "Strain."

Tensile Strength.—Same as "Tensile Resistance," *q.v.*

Tensile Stress.—See "Stress."

Tension.—The state or condition of being stretched.

Direct Tension.—Tension applied parallel to the axis of the member and uniformly over its cross-section.

Initial Tension.—Tension applied to a member before it is subjected to the principal load.

Tension Bar.—See "Bar."

Tension Beam.—See "Beam."

Tension Bolt.—See "Bolt."

Tension Brace.—See "Brace."

Tension Joint.—See "Joint."

Tension Member.—See "Member."

Tension Rod.—See "Rod."

Ten-wheeled Locomotive.—See "Locomotive."

Teredo Navalis.—A worm-shaped, marine mollusc having a shell with two small valves at its head with which it bores into submerged wood.

Terra Cotta.—A hard pottery used for building purposes.

Test.—A method for determining the properties of a material. The act of testing.

Bending Test.—A test made by bending bars to determine their comparative brittleness. A test made on beams to determine their moduli of rupture.

Boiling Test.—A test for determining the constancy of the volume of cement. Pats of cement mortar are made, protected against drying for twenty-four hours, then put in hot water or steam for five hours, after which they are removed and observed for signs of cracking and disintegration. If no such signs appear, the cement has proved satisfactory in respect to soundness.

Heat Test.—Same as "Boiling Test," *q.v.*

Specimen Test.—A test of a portion of the material to be used in the construction of a structure.

Test Bar.—See "Bar."

Testing Machine.—A machine provided with the mechanism for exerting a force on a specimen of some material and thereby determining its properties.

Test Piece.—A piece, portion, or specimen of any material, used for testing or determining its qualities and properties.

Test Pile.—See "Pile."

Thacher's Slide Rule.—See "Slide Rule."

Theorem of Three Moments.—See "Moment."

Thickening Washer.—See "Washer."

Thimble.—A sleeve or bushing used to join the ends of pipes, shafting, etc.; or to fill an opening, or to cover an axle.

Thimble Coupling.—Same as "Sleeve Coupling." See "Coupling."

Thimble Joint.—See "Joint."

Thinner.—A liquid, such as turpentine, which is added to paint in order to thin it, or to reduce its viscosity. Should be used with great caution in bridge painting.

Non-volatile Thinner.—That portion of the thinner which is not volatilized by a current of steam at atmospheric pressure.

Volatile Thinner.—All that liquid portion of a paint, water excepted, which is volatilized in a current of steam at atmospheric pressure.

Third-class Masonry.—See "Masonry."

Thoroughfare.—Any street, alley, watercourse, or passageway used for public travel of any kind.

Thread.—The helix cut on the shank of a bolt or screw.

Left-handed Thread.—A spiraling in such a direction that a counter-clockwise rotation of the bolt or screw produces a forward motion of the bolt.

Pitch of Thread.—See "Pitch."

Pressed Thread.—A thread made by pressing instead of cutting.

Right-handed Thread.—A spiraling in such a direction that a clockwise rotation of the bolt or screw produces a forward motion of the bolt.

Screw Thread.—The thread on a screw, having a cross-section like an inverted V.

Square Thread.—A thread having a square or rectangular cross-section.

Standard Thread.—A thread having the shape of spiraling and a pitch conforming to some standard such as the American Bridge Company's Standard Thread.

V-Thread.—A thread having a cross-section like an inverted letter V.

Thread Cutter.—See "Cutter."

Three-hinged Arch.—See "Arch."

Through Bolt.—See "Bolt."

Through Bridge.—See "Bridge."

Through Cantilever.—See "Cantilever."

Through Girder.—See "Girder."

Through Span.—See "Span."

Through Truss.—See "Truss."

Thrust.—To push. The amount of push.

Horizontal Thrust.—A thrust in a horizontal direction, as that of a braked train.

Longitudinal Thrust.—A thrust along the longitudinal axis of a member.

Thrust Angle.—See "Angle."

Thrust Axle.—See "Axle."

Thrust Bearing.—See "Bearing."

Thrust Collar.—See "Collar."

Thrust of an Arch.—See "Arch."

Thumb Nut.—See "Nut."

Thumb Screw.—See "Screw."

Tide Gauge.—See "Gauge."

Tie.—A piece of timber used in railroads for supporting and holding the rails together. A sleeper. A tension member of a truss.

Beveled Tie.—A railroad tie in which the top and the bottom faces are closer together at one end than at the other.

Cross Tie.—A railroad tie or sleeper.

Diagonal Tie.—A tension diagonal incapable of resisting compression.

Doty Tie.—A timber tie affected by a certain fungous disease.

Half Round Tie.—A slabbed tie having greater width on the lower than on the top face.

Heart Tie.—A railroad tie showing sapwood on one or two corners only and which sapwood does not measure more than one inch on either corner on lines drawn diagonally across the end of the tie.

Hewed Tie.—A railroad tie which is hewed on at least two sides.

Pecky Tie.—A tie made from a cypress tree that is affected with a fungous disease, known locally as peck.

Pole Tie.—A tie made from a tree of such size that not more than one tie can be made from a section—hewed or sawed on two parallel faces.

Quartered Tie.—A tie made from a tree of such size that four ties only can be made from a section.

Sap Tie.—A tie which shows more than the prescribed amount of sapwood in cross-section.

Slab Tie.—A tie made from a slab.

Slabbed Tie.—A tie sawed on the top and bottom only.

Split Tie.—A tie made from a tree of such size that, by splitting, two or more ties can be made from a section.

Strict Heart Tie.—A tie having no sapwood.

Sub-tie.—A tension member in a subdivided panel of a truss.

Treated Tie.—A tie which has been subjected to a preservative process, such as saturation with creosote under heat and pressure.

Wane Tie.—A square tie showing part of the original surface of the tree on one or more corners.

Tie Bar.—See "Bar."

Tie Beam.—See "Beam."

Tie Bolt.—See "Bolt."

Tie Hammer.—See "Hammer."

Tie Line.—See "Line."

Tie Plate.—Same as "Batten Plate." See "Plate."

Tier.—A row or series. Restricted to vertical direction. A vertical division or paneling in a trestle tower.

Tie Rod.—See "Rod."

Tie Spacing.—The interval between ties. Also the distance from centre to centre of ties.

Tile.—An earthenware pipe used for drainage.

Bonanza Tile.—A reinforced composition cement tile used in roofing.

Crown Tile.—A roofing tile used at the hips or ridges of roofs.

Tile Floor.—See "Floor."

Tilt.—To forge with a tilt hammer.

Tilt Hammer.—See "Hammer."

Timber Bent.—Same as "Frame Bent," *q.v.*

Timber Bolt.—See "Bolt."

Timber Buggy.—See "Buggy."

Timber Casing.—See "Casing."

Timber Coupling.—See "Coupling."

Timber Dogs.—See "Dog."

Timber Floor.—See "Floor."

Timber Jack.—See "Jack."

Timber Joists.—See "Joists."

Timber Hitch.—A kind of knot. See "Knot."

Timber Hitch and a Half-hitch.—See "Knot."

Timber Hook.—Same as "Timber Dog." See "Dog."

Timber Lath.—See "Lath."

Timber Lathe.—See "Lathe."

Timber Pier.—See "Pier."

Timber Truck.—A frame mounted on four wheels which run on rails, used for transporting timber short distances. Any small, wheeled apparatus for moving timber.

Timber Strut.—See "Strut."

Tint.—A color produced by the admixture of a coloring material not white, with a white pigment or paint, the white predominating.

Tinting Strength.—The power of coloring a given quantity of paint or pigment selected as a medium standard for estimating such power.

Tipper.—A type of draw span supported at each of the two ends of the centre panel by a beam which, in turn, rests upon wedges or cams. The arrangement is such as to produce an equal reaction at each support under the bearings of the trusses.

T-Iron.—See "Iron."

Tit.—A small accidental projection on a casting. Spelled also "Teat."

Tit Drill.—See "Drill."

Toe.—The foot of a slope. The front part of the base of an abutment or retaining wall.

Toe-nail.—To fasten a board or timber to the surface of another by driving nails obliquely through the end or edge of the first timber and into the second.

Toggle.—A mechanical device consisting of two bars or plates hinged together at their common ends and pivoted at the other ends; used for transmitting a force laterally to its line of application.

Toggle Bolt.—See "Bolt."

Toggle Iron.—See "Iron."

Toggle Joint.—See "Joint."

Toggle Riveter.—See "Riveter."

Ton.—A unit of weight, generally equal to two thousand pounds.

Foot Ton.—A unit of work equal to that involved in overcoming one ton of resistance through the space of one foot, or in raising one ton one foot high.

Inch Ton.—A unit of work equal to that involved in raising one ton one inch high.

Long Ton.—A unit of weight equal to 2,240 pounds, generally employed for coal and steel rails. It is the English ton.

Metric Ton.—A French ton, equivalent to 2,205 pounds nearly.

Short Ton.—A ton of two thousand pounds.

Tone.—The color which principally modifies a hue or a white or black.

Ton-foot.—Same as "Foot-ton," *q.v.*

Tongs.—A tool for grasping objects, consisting of two flat, curved bars pivoted about a common centre.

Hammer Tongs.—A pair of tongs which is designed for picking up the handles of tools or hammer heads which are red hot.

Pipe Tongs.—A hand tool for grasping and turning pipes, consisting of two specially bent bars forming a jaw near one end, where it works on a pivot, and having the other end fashioned into handles.

Rail Tongs.—Tongs with hooked ends and spreading handles, used for carrying rails.

Rivet Tongs.—Tongs used by riveters for throwing and placing hot rivets.

Tongue and Groove.—A term applied to lumber in which one edge of a board has a recess for receiving the projecting tongue of the adjacent board, while the opposite edge has a projecting tongue to fit into the recess of the next board.

Tongued and Grooved Joint.—See "Joint."

Tongue Joint.—See "Joint."
Tongue Plate.—See "Plate."
Tool.—Any thing, device, or apparatus used to facilitate mechanical operations; usually restricted to small implements.
  Balling Tool.—A hand tool used for collecting into a mass the iron in a puddling furnace.
  Calking Tool.—A tool used for the process of calking.
  Cutting Tool.—A tool used for cutting materials.
  Heading Tool.—A tool for the swaging of bolt heads.
  Radius Tool.—A tool used by cement finishers to form a round corner on exposed concrete work.
Tool Box.—See "Box."
Tool Chest.—A chest or covered box for the storing or shipping of tools.
Tool Dressing.—See "Dressing."
Tooled Ashlar.—See "Ashlar."
Tool Finish.—Same as "Tool Dressing," *q.v.*
Tool House.—A house for the storage and safe-keeping of tools.
Tooling.—The act of operating with a tool upon an object.
Tool Steel.—See "Steel."
Tooth.—The projection or cog on a gear wheel which meshes with a like projection on another similar gear.
  Epicycloidal Tooth.—A form of gear tooth having both faces and flanks curved to conform with arcs of an epicycloid.
  Face of Gear Tooth.—The part of the rolling surface of a gear tooth outside the pitch circle.
  Flank of Gear Tooth.—The part of the rolling surface of a gear tooth inside the pitch circle.
  Involute Tooth.—A form of gear tooth in which the faces conform to an arc of an involute and the flanks to radial planes.
  Point of Gear Tooth.—The outer end of a tooth on a gear wheel.
  Rack Tooth.—The tooth on a rack which meshes with a gear.
  Root of Tooth.—The base of the tooth where it joins the rim of the wheel.
Tooth Axe.—See "Axe."
Tooth Axed Dressing.—A form of stone dressing. See "Dressing."
Toothed Chisel.—See "Chisel."
Toothed Dressing.—See "Dressing."
Toothed Wheel. -See" Wheel."
Toothing.—A general term for a system of teeth.
Tooth Pitch.—Same as "Circular Pitch."
Tooth Pressure.—See "Pressure."
Top Chord.—See "Chord."
Top Lateral Bracing.—See "Bracing."
Topographical Map.—See "Map."
Torque.—The moment of a force or a system of forces tending to produce rotation. The starting capacity of a rotative machine.
Torsion.—The twist or deformation of a body set up by a torque.
  Angle of Torsion.—The amount of twist or deformation produced by a torque.
  Coefficient of Torsion.—The angle of torsion produced in a wire of unit dimension by a force acting with unit moment.
  Moment of Torsion.—The sum of all the moments of the internal forces in a body that is resisting a twisting moment. It is equal to the sum of the moments of all the applied forces that tend to produce torsion
Torsional Strain.— See "Strain."
Torsional Stress.— See "Stress."

Total Energy.—See "Energy."
Total Haul.—See "Haul."
Total Splice.—See "Splice."
Total Stress.—See "Stress."
Touch Micrometer.—See "Micrometer."
Tow.—A boat or barge, or a collection of boats or barges, hauled by another vessel. A raft of logs hauled by a power vessel.
Tower.—See "Post."
Tower.—A vertical structure consisting of two or more bents of framework connected by bracing."
Tower Bracing.—See "Bracing."
Tower Panel.—See "Panel."
Tower Span.—See "Span."
Tower Truss.—See "Truss."
Tracing.—A drawing made on transparent cloth. The act of copying on tracing cloth a drawing placed beneath.
Tracing Cloth, or Tracing Linen.—A fine linen fabric covered with a gelatinous material or sizing making it transparent so that it can be used for copying drawings.
Tracing Paper.—See "Paper."
Track.—A set of rails or plates and their supports on which may be rolled a body or structure provided with wheels or rollers.
Double Track.—A track consisting of two pairs of rails.
Lorry Track.—A track on which a lorry runs, usually a narrow-gauge track found around blast furnaces and coal tipplers.
Side Track.—A secondary track parallel to and connected with the main track of a railroad.
Single Track.—A track with a single pair of rails.
Spur Track.—A short track leading from the main track and connected to it at one end only.
Track Bolt.—See "Bolt."
Track Gauge.—See "Gauge."
Track Jack.—See "Jack."
Track Joists.—See "Joist."
Track Maul.—See "Maul."
Track Pile-driver.—See "Pile-driver."
Track Rail.—See "Rail."
Track Segment.—See "Segment."
Track Spacing.—The arrangement of tracks with respect to each other. The distance between track centres of adjacent tracks.
Track Spike.—See "Spike."
Track Stringer.—See "Stringer."
Track Tie.—Same as "Cross Tie," See "Tie."
Track Walker.—A man who makes regular inspection trips along the track by walking.
Track Wrench.—See "Wrench."
Traction.—The force required to draw a body. The adhesive resistance of a driving-wheel on a rail.
Traction Bracing.—Same as "Train Thrust Bracing." See "Bracing."
Traction Load.—See "Load."
Traction Stress.—See "Stress."
Traction Thrust.—Same as "Traction Load," *q.v.*
T-Rail.—See "Rail."
Train Thrust Bracing.—See "Bracing."
Tram.—A small car used on a tramway.
Tram Crane.—Same as "Traveling Crane."

Trammel.—A drawing instrument for describing circles of large radii, consisting of a bar and two sliding parts which can be adjusted to the desired radius by sliding them along the bar. One sliding part is provided with a point for centering and the other with a pen or pencil for drawing the curve. Called also a "Beam Compass."

Tramway.—A temporary track built near a bridge and used in connection with tramcars for transporting materials to the work.

Transcendental Curve.—See "Curve."

Transferred Load.—See "Load."

Transferred Load Stress.—See "Stress."

Transformed Catenary.—See "Catenary."

Transit.—An engineer's instrument for running lines, measuring or laying off angles, obtaining differences in elevations, etc., in field work. It consists of a telescope mounted on a horizontal axle and capable of a complete revolution. The standards supporting the axle are attached to a horizontal plate capable of rotation in its own plane. These two rotations permit of the measurement of vertical and horizontal angles and the projection of a line in any direction.

Transition Curve.—Same as "Easement Curve." See "Curve."

Transitman.—The man who operates the transit.

Transit Point.—A point over which the transit is set.

Transverse.—Extending across. Crosswise direction.

Transverse Beam.—See "Beam."

Transverse Bracing.—See "Bracing."

Transverse Component.—See "Component."

Transverse Girder.—See "Girder."

Transverse Line.—See "Line."

Transverse Load.—See "Load."

Transverse Section.—See "Section."

Transverse Shear.—See "Shear."

Transverse Strain.—See "Strain."

Transverse Stress.—See "Stress."

Transverse Vertical Bracing.—Same as "Transverse Bracing," *q.v.*

Trap.—A hard, dark-colored, volcanic rock used for concrete roadway pavements, and ballast for railroads. Also a device that will intercept material in flowing water.

Sand Trap.—A device for separating sand from water.

Trass.—A gray, yellow, or whitish earth made up in large part of comminuted pumice or other volcanic material. Resembles pozzuolana. Used for making hydraulic cement.

Traveler.—A form of derrick mounted on wheels, used in the erection of bridges.

Creeper Traveler.—A small movable derrick running on a track on the upper chord of a truss. It usually has two booms. A mule traveler.

Gantry Traveler.—A framework of two or three bents or gallows frames, braced longitudinally and carried on a track supported on falsework and placed outside of the trusses. The traveler clears the span at all points and can be rolled back and forth as needed. It carries a number of blocks and tackles which are operated by a hoisting engine placed on a platform near the base. It is used in erection for hoisting and placing the members of a truss.

Traveler Wheel.—See "Wheel."

Traveling Crane.—See "Crane."

Traveling Girder.—See "Girder."

Traverse Line.—See "Line."

Tread.—The bearing surface of a wheel or of a rail. The steps of a stairway.

Treated Tie.—See "Tie."

Treated Timber.—Timber which has been subjected to a preservative process.

Treenail.—A cylindrical pin of hard wood used to fasten timbers together.

Trémie.—A long tube or box used for depositing concrete under water by a process of continuous filling at the upper end and discharging at the lower, accomplished by a slight churning motion.

Trench.—A long, narrow excavation.

Trestle.—A bridge structure composed of bents or towers and supporting stringers or girders forming the floor system.

Framed Trestle.—A trestle having framed bents.

Knee-braced Trestle.—A trestle provided with knee braces.

Pile Trestle.—A trestle having pile bents for supporting the deck.

Trestle Bent.—See "Bent."

Trestle Bridge.—See "Bridge."

Trestle Cap.—See "Cap."

Trestle Work.—See "Work."

Triangle.—A figure bounded by three straight sides.

Force Triangle.—A system of three forces in equilibrium represented by three sides of a triangle drawn parallel and with lengths proportional to the respective forces.

Triangular File.—See "File."

Triangular Girder.—See "Girder."

Triangular Lattice Truss.—See "Truss."

Triangular Scale.—See "Scale."

Triangular Truss.—See "Truss."

Triangulation.—The process of locating points or determining distances by a system of triangles constructed on a measured base line, permitting the measurement of adjacent angles.

Triangulation Hub.—See "Hub."

Triangulation Point.—The point at the corner of the triangle over which the transit is set in order to measure the angle.

Triangulation Sheet.—The drawing upon which is shown the triangulation system for a bridge with the dimensions thereof.

Tricalcic-silicate.—The chief constituent of Portland cement, which is the active element composed of calcium, oxygen, and silicon, as defined by the chemical formula $3CaO.SiO_2$.

Trigonometric Function.—See "Function."

Trip.—A device for tripping or releasing a hammer, or for opening a collapsible bucket.

Trip Hammer.—See "Hammer."

Triple Block.—See "Block."

Triple Cancellation.—See "Cancellation."

Triple Intersection.—Same as "Triple Cancellation." See "Cancellation."

Trip Line.—See "Line."

Tripod.—An arrangement of three legs pivoted to a headpiece, used for supporting an instrument such as a transit or a level.

Trolley.—A small flanged wheel arranged to run upon a wire or rod.

Trough Floor.—See "Floor."

Trough Plate.—See "Plate."

Trough Plate Floor.—See "Floor."

Trowel.—A mason's tool consisting of a handle and a flat triangular-shaped blade for handling mortar.

Hand Float Trowel.—A form of trowel having squared ends and the handle between them.

Troweled Finish.—See "Finish."

Troy Rod.—See "Rod."

Truck.—A small vehicle consisting of a frame mounted on two or four wheels. A group of four or more wheels in a frame supporting one end of a railway car.

Truck.

Bogie Truck.—A railway truck mounted on two or more pairs of wheels and attached to a car or locomotive engine by means of a vertical king pin about which it turns so as to facilitate the rounding of curves in the track.

Timber Truck.—A frame mounted on four wheels which run on rails. Used for transporting timber. Any small wheeled apparatus for moving timber.

Truck Jack.—See "Jack."

True Discount.—See "Discount."

True Horsepower.—Same as "Indicated Horsepower." See "Horsepower."

True Stress.—See "Stress."

Truncated Bow String Truss.—See "Truss."

Trundle.—Same as "Lantern Wheel," *q.v.*

Trunnion.—A form of short axle attached to the side of a body.

Trunnion Bascule Bridge.—See "Bascule."

Truss.—A framed or jointed structure designed to act as a beam while each of its members is primarily subjected to longitudinal stress only.

A-Truss.—A four-panel truss having extended batter posts intersecting over the centre resembling somewhat the letter A. See Fig. 22*dd*.

Arch Truss.—A truss having an arched upper chord in compression and a straight bottom chord or tie rod with vertical hangers.

Baltimore Truss.—A truss composed of parallel chords and subdivided panels. See Figs. 22*c* and 22*d*.

Bollman Truss.—A trussed beam, each panel-load being carried directly to the ends of the upper chord by two inclined tension members, there being no stress in the lower chord. Properly speaking, it is not a truss, but a multiple suspension system. See Fig. 22*o*.

Bowstring Truss.—A truss in which the lower chord is horizontal and the upper chord joints lie in the arc of a parabola, or similar curve. See Fig. 22*s*.

Bridge Truss.—Any truss used in a bridge span.

Burr Truss.—A timber truss with counter-struts inserted throughout the entire length giving very great rigidity.

Camel-back Truss.—A truss having a broken outline for the upper chord taking the humped shape of a camel's back. See Figs. 22*ee* and 22*ff*.

Cantilever Arch Truss.—A cantilever truss having the shape of a portion of an arch.

Cantilever Truss.—A truss overhanging its support at one end and anchored down at the other.

Continuous Truss.—A truss which extends over three or more supports.

Crescent Truss.—A truss with both chords curved upward, or both downward, and making sharp intersections with each other at the ends, producing in outline the appearance of a crescent, the web system being of the triangular type.

Deck Truss.—A loose expression for the truss of a deck span.

Double Bowstring Truss.—A truss in which the joints of each chord lie in curves concave to each other. See Fig. 22*r*.

Double Intersection Truss.—A truss having two intersecting diagonals for each panel. See Fig. 22*i*.

Double Triangular Truss.—Same as "Double Intersection Truss," *q.v.*

Fink Truss.—Properly, a trussed beam. See Fig. 22*n*.

Half-through Truss.—A loose expression for the truss of a half-through span.

Hog-chain Truss.—Properly a trussed beam. Same as an inverted "Queen Post Truss," *q.v.*

Horizontal Truss.—A truss placed in a horizontal plane.

Howe Truss.—A form of truss in which the vertical members of the web take tension and the diagonal members compression. See Fig. 22*p*.

Intermediate Truss.—The centre truss of a three-truss span.

Truss.

Joggle Truss.—A type of timber truss in which the members are connected by joggles, *q.v.* Also a truss having only one joint.

Kellogg Truss.—A variation of the Pratt truss. See Fig. 22*bb*.

King Post Truss, or **King Truss.**—Properly a trussed beam with one vertical post at centre.

K.-Type Truss.—See Figs. 22*gg* and 22*hh*

Lattice Truss.—A truss having several web systems. See Fig. 22*t*.

Lenticular Truss.—Same as "Double Bowstring Truss," *q.v.* See Fig. 22*r*.

Linville Truss.—Same as "Whipple Truss," *q.v.*

Multiple Truss.—A truss having a multiple cancellation web system.

Murphy Truss.—A Whipple Truss having eye-bars for the lower chords.

Palmer Truss.—Same as "Burr Truss," *q.v.*

Parabolic Truss.—A bow-string truss having the upper chord joints lying in a parabola. See Fig. 22*s*.

Parker Truss.—A name sometimes used for the Pratt Truss when the upper chord is polygonal. See Fig. 22*b*.

Pegram Truss.—A form of truss having the panel points of the upper chord lying in the arc of a circle and inclined web members. See Fig. 22*cc*.

Pennsylvania Truss.—A Petit truss with an inclined chord. See Figs. 22*e* and 22*f*.

Petit Truss.—A modified form of the Pratt truss having subdiagonals. See Figs. 22*c*, 22*d*, 22*e*, and 22*f*.

Pin-connected Truss.—Any truss having its main members joined by pins.

Pony Truss.—A low truss without any overhead bracing.

Post Truss.—See Fig. 22*q*.

Pratt Truss.—A type of truss having parallel chords and an arrangement of web members of tension diagonals and compression verticals. See Fig. 22*a*.

Primary Truss.—A main truss which supports smaller trusses.

Quadrangular Truss.—Same as "Pratt Truss," *q.v.*

Queen Post Truss.—A type of trussed beam having two vertical posts.

Riveted Truss.—Any truss having its main members riveted together.

Roof Truss.—Any truss used in supporting a roof.

Schwedler Truss.—A modification of the Whipple Truss. See Fig. 22*aa*.

Secondary Truss.—A truss supported by another truss.

Single Intersection Truss.—A truss with one web system only. See Fig. 22*g*.

Stiffening Truss.—A truss used in connection with a suspension cable to distribute the load over the length thereof.

Subdivided Warren Truss.—A Warren truss with verticals having subdiagonals and subverticals. It bears the same relation to Fig. 22*l* as the Petit truss does to the Pratt truss.

Through Truss.—A loose expression for a truss of a through span.

Town Truss.—A form of lattice truss having double chord systems and two web systems in different planes. See Fig. 1*f*.

Triangular Lattice Truss.—See Fig. 22*t*.

Triangular Truss.—A truss having inclined web members. See Fig. 22*g*.

Truncated Bow-string Truss.—A bow-string truss with squared ends.

Warren Truss.—A form of triangular truss composed of equilateral triangles. See Fig. 22*k*.

Whipple Truss.—A double intersection Pratt truss. See Fig. 22*z*.

Wind Truss.—A truss to carry a wind load.

Windward Truss.—The truss next to the wind.

Truss Block.—See "Block."

Truss Bridge.—See "Bridge."

Truss Deformation.—See "Deformation."
Truss Depth.—See "Depth."
Trussed Arch.—Same as "Braced Arch," *q.v.*
Trussed Beam.—See "Beam."
Trussed Eye-bars.—See "Eye-bar."
Trussed Girder.—See "Girder."
Truss Element.—See "Element."
Truss Girder.—See "Girder."
Trussing.—A system of rods attached to the ends of a beam, girder, or column and held therefrom by short struts between the member and the rods.
Truss Joint.—See "Joint."
Truss Member.—Same as "Truss Element," *q.v.*
Truss Pin.—See "Pin."
Truss Rod.—See "Rod."
Truss Shop.—A shop where bridge trusses are manufactured.
Truss Spacing.—The perpendicular distance between the central planes of trusses of a bridge.
Truss Span.—See "Span."
T-Square.—See "Square."
Tube.—A pipe of small size. A hollow cylinder.
Guide Tube.—A contrivance by which a boring bit or drill is guided, commonly a fixed tube to prevent swinging.
Tube-mill.—A shop where tubes are drawn.
Tubular Arch Bridge.—See "Bridge."
Tubular Bridge.—See "Bridge."
Tubular Girder.—See "Girder."
Tuck Joint.—See "Joint."
Tug.—A small, powerful boat for towing.
Tumbler.—Same as "Rattler," *q.v.*
Tungsten Steel.—See "Steel."
Tunnel.—An excavated passageway under the ground or the water.
Tup.—A ram.
Turnbuckle.—A device for tightening or drawing together two parts of a rod, consisting of a sleeve having an interior right-hand thread at one end and an interior left-hand thread at the other. This sleeve engages the threaded ends of the two pieces of rod so that a turning thereof in one direction screws up on the rods and in the reverse direction unscrews on them.
Turned Bolt.—See "Bolt."
Turned Shafting.—See "Shafting."
Turning Bridge.—Same as "Swing Bridge." See "Bridge."
Turning Point.—A point of reference on some firm object, used in levelling for resetting the instrument.
Turnout.—A railroad switch or siding.
Turnstile.—A revolving gate.
Turntable.—The framework under the swing span which transmits the load to the bearings.
Centre-bearing Turntable.—A turntable having a centre pivot for supporting the load during operation.
Double Rim-bearing Turntable.—A turntable comprising two concentric circular girders or rims, each transferring its part of the load to an independent set of rollers.
Rim-bearing Turntable.—A turntable having a circular girder, or rim, to transfer the load to a set of rollers.
Turntable Girder.—See "Girder."

Turpentine.—An oleoresin exuding from several varieties of coniferous trees, used as a thinner in mixing paints.

Tuyère.—A tube or pipe through which air is blown directly into a blast furnace.

Twist.—A rotation of one body about another, or of a part of a body about another part of the same body.

Angle of Twist.—Same as the "Angle of Torsion," *q.v.*

Twist Drill.—See "Drill."

Twist Drill Grinder.—An emery wheel mounted on a shaft in a frame having an adjustable rest for holding the twist drill during grinding.

Twisting Moment.—Same as "Torque," *q.v.*

Twist Joint.—See "Joint."

Two-blocks.—An expression used by bridge erectors in hoisting to signify that a stopping point or limit has been reached; derived from the condition of a block and tackle being overhauled until the two blocks come together when no further motion in the same direction is possible. A synonym for this is "Chock-a-block."

Two-hinged Arch.—See "Arch."

U

U-Abutment.—See "Abutment."

U-Bolt.—See "Bolt."

Ultimate Resistance.—See "Resistance."

Ultimate Strength.—Same as "Ultimate Resistance." See "Resistance."

Ultimate Stress.—See "Stress."

Unbalanced Bid.—See "Bid."

Unbalanced Load.—See "Load."

Unbalanced Wheel.—See "Wheel."

Uncoursed Rubble.—Same as "Random Rubble." See "Rubble."

Underdrain.—To drain by forming channels underground.

Undermine.—To excavate beneath a structure.

Underpin.—To pin or support an existing wall by excavating at intervals beneath it and building in piers, after which further excavation is made between the piers and the spaces then are filled with solid walls.

Underpinning.—The process of placing underpins. The collective name for the group of underpins.

Unequal Coursing.—Same as "Random Coursing." See "Course."

Unfilleted.—Without fillets. Sharp cornered.

Uniform Load.—See "Load."

Uniform Load Stress.—See "Stress."

Uniform Resistance.—See "Resistance."

Uniform Section.—See "Section."

Uniform Strength.—Same as "Uniform Resistance," *q.v.*

Uniform Stress.—See "Stress."

Union.—A form of coupling, used for connecting two pieces of pipe.

Flange Union.—A type of pipe connection consisting of two circular plates with hubs bored and tapped to screw on the ends of the pipes, and held together with bolts.

Pipe Union.—A form of pipe connection, employed for making a closure in a system of pipes. Its essential features are two end pieces which screw on the pipe ends and fit into each other, also an outer ring or sleeve having an inner shoulder at one side, which bears against one of the end pieces as the ring is turned and screwed on the other end piece, thus pulling the two ends together.

Union Joint.—See "Joint."

Unit Cost.—See "Cost."

Unit Price.—The price per unit of magnitude, such as the price per hour, per ton, per square foot, per cubic yard, etc.

Unit Stress.—See "Stress."

Unit Weight.—The weight per unit of magnitude, as the weight per cubic foot.

Universal Grinder.—A grinding machine having an emery wheel mounted on a shaft with a universal joint admitting of a swinging motion in any direction.

Universal Joint.—See "Joint."

Universal Mill.—See "Mill."

Universal Mill Plate.—See "Plate."

Unreeve.—To withdraw a rope from a set of blocks.

Unstable.—Not fixed; not in permanent equilibrium.

Unsupported Length.—See "Length."

Unsupported Width.—The width of a plate between the nearest points of lateral restraint.

U-Nut.—See "Nut."

Uphead.—Same as "Upset," *q.v.*

Uplift.—The tendency of a structure, due to special loading conditions, to rise from its supports. Negative reaction.

Uplift Stress.—See "Stress."

Upper Chord.—Same as "Top Chord." See "Chord."

Upper Deck.—See "Deck."

Upper Laterals.—Same as "Top Laterals." See "Laterals."

Upper Falsework.—See "Falsework."

Upper Lateral Bracing.—See "Bracing."

Upper Lateral Rod.—Any rod in the upper lateral system. See "Lateral Rod."

Upper Laterals.—See "Lateral."

Upper Lateral Strut.—Any strut in the upper lateral system.

Upper Track.—In rim-bearing draw spans, the plate attached to the bottom of the rim and bearing on the rollers.

Upper Track Segment.—One of the pieces composing the upper track.

Upset.—To thicken a piece of metal by heating and hammering on the end.

Upset-end.—The end of a bar or rod which has undergone the process of upsetting.

Upset Rod.—See "Rod."

Upward Reaction.—See "Reaction."

Uses.—A rough block to be made into small forgings.

V

Vacuum Process.—An abandoned process for sinking piers. Its essential feature was the intermittent loading of the caisson by suddenly withdrawing the air from the working chamber, leaving the outside atmospheric pressure unbalanced, and thereby giving a downward impulse to the caisson. See "Trautwine" for details.

Valley.—A re-entrant angle formed by the intersection of two parts of a roof.

Valve.—A device for closing the passageway in a pipe, duct, or conduit.

Air Valve.—A valve controlling the passage of air. Also a valve admitting air to a steam boiler, preventing the formation of a partial vacuum when the steam condenses.

Ball Check Valve.—A check valve formed by a ball resting upon a concave circular seat.

Ball Valve.—A valve controlled by a float ball. A valve formed by a ball resting upon a concave circular seat, a form of check valve.

Centre Valve.—A four-way valve.

Check Valve.—A valve arranged to permit a flow in one direction only, thereby preventing the return of the fluid.

Clack Valve.—A valve hinged at one end so as to permit the flow of the liquid in one direction only.

Valve.

Clapper Valve.—A form of check valve used in pneumatic work to prevent the escape of air from the working chamber when the compressor shuts down.

Coupling Valve.—See "Coupling Valve."

Crown Valve.—A crown-shaped valve sliding over a slotted box, such as the slide valve in a steam engine.

Discharge Valve.—A valve through which a fluid is discharged.

D-Valve.—Same as "Slide Valve," *q.v.*

Flap Valve.—Same as "Check Valve," *q.v.*

Gate Valve.—A valve having a slide or gate placed at right angles to the flow of the liquid and arranged to draw completely to one side when opened, thereby offering little obstruction to the flow, but completely stopping it when closed.

Globe Valve.—A valve having an exterior form like a globe and an interior movable disk, parallel to the flow, fitting into a circular seat in a bent partition inside the globe.

Head Valve.—The upper air-pump valve of a condensing steam engine.

Hydraulic Valve.—Any valve controlling the flow of water.

Leaf Valve.—Same as "Clack Valve," *q.v.*

Lever Valve.—A valve having a lever and weight attached to keep it closed until the pressure on its disk exceeds a predetermined amount, at which time it opens and permits some of the fluid to escape. An old form of safety valve, used on steam boilers.

Piston Valve.—A reciprocating valve, having the form of a piston working in a tubular passage, which opens and closes successively the ports of a cylinder of a steam engine.

Receiving Valve.—A valve admitting the flow of a liquid.

Slide Valve.—A valve having a reciprocating motion, used in engines to open successively the admission and the exhaust ports.

Stop Valve.—Same as "Gate Valve," *q.v.*

Vanadium Steel.—See "Steel."

Van Dyke Print.—A positive print taken from a negative print in the same color.

Vanishing Point.—A point in perspective drawing where parallel lines appear to intersect the ground line or horizon.

Varnish.—A solution of certain gums or resins in alcohol or linseed oil; used by painters to produce a hard, transparent coat or surface.

Vehicle.—An oil or other medium used by painters for carrying the pigment of a paint. Any apparatus for carrying loads.

Non-volatile Vehicle.—The liquid portion of a paint, excepting only its volatile thinner and water.

Velocity.—The rate of motion.

Angular Velocity.—The rate of angular motion.

Lineal Velocity.—The rate of lineal motion.

Virtual Velocity.—See "Virtual."

Vent or **Vent-hole.**—An outlet or passage for fluids.

Vermiculated.—Tortuous or sinuous like a worm.

Vermiculated Dressing.—See "Dressing."

Vernier.—A small movable scale running parallel to a fixed scale and graduated so that $n + 1$ or $n - 1$ parts on the vernier are equal to n parts of the primary scale.

Vernier Calipers.—See "Calipers."

Vernier Plate.—See "Plate."

Vertex.—The highest point, crown, or apex.

Vertical.—Upright, plumb, perpendicular to the horizon. Also an upright member in a truss.

Vertical.

Hip Vertical.—The upright tension member attached to the pin or to the plates at the hip of a truss and carrying a floor beam at its lower end.

Sub Vertical.—The upright member in a subdivided panel running from midpanel point to the chord.

Vertical Bracing.—See "Bracing."

Vertical Clearance.—See "Clearance."

Vertical Curve.—See "Curve."

Vertical Lift Bridge.—See "Bridge."

Vertical Line.—See "Line."

Vertical Strut.—See "Strut."

Viaduct.—An extended bridge of many spans, mainly over dry ground. Usually consists of alternate towers and open spaces or bays.

Vibration.—A movement back and forth. A form or mode of motion in which the moving particle occupies successive positions in recurrence.

Amplitude of Vibration.—The maximum movement or displacement of any particle that vibrates.

Cumulative Vibration.—A piling up or a superposing of vibration. An increasing vibration.

Period of Vibration.—The time required for the vibrating particle to make one complete movement back and forth.

Vibration Rod.—See "Rod."

Vibratory Stress.—See "Stress."

Vicat Needle.—A small definitely weighted needle having a point of a definite, prescribed area; used in testing the activity of cement.

Virginia Hemp.—See "Hemp."

Virtual Moment.—A term applied to the product of a force by its virtual velocity.

Virtual Velocity.—An arbitrary, infinitesimal displacement of the point of application of a force resolved into the line of action of the said force. The term is a misnomer, for it has nothing whatsoever to do with velocity.

Vise.—An appliance or tool for gripping and holding an object, consisting of two jaws and a screw with a handle for forcing the jaws together.

Anvil Vise.—A vise with an anvil on the fixed jaw.

Bench Vise.—A vise constructed so that it may be attached to a bench.

Hand Vise.—A small vise to be held in the hand while gripping the object.

Pipe Vise.—A vise with jaws notched to receive a pipe.

Vitrifaction, or **Vitrification.**—The act of vitrifying.

Vitrified Brick.—See "Brick."

Vitrify.—To convert into glass by the application of heat.

Voids.—The spaces between the particles of a substance or of a mixture; used in connection with sand, broken stone, or gravel for concrete.

Percentage of Voids.—The ratio of the unfilled space to the total space in an aggregate, expressed as a percentage.

Volatile Thinner.—See "Thinner."

Voltmeter.—An electrical instrument for measuring a drop in voltage or the difference in potential between two points in a circuit.

Volume.—The space occupied by an object.

Volumenometer.—An apparatus for measuring the volume of a solid body by determining the quantity of fluid which it displaces.

Volumetric Modulus of Elasticity.—See "Elasticity."

Vortex.—A whirlpool or eddy in a fluid.

Voussoir.—A stone or block in the shape of a truncated wedge which forms part of an arch ring.

V-Thread.—See "Thread."

Vug.—A cavity in a casting.

Vulcanize.—To treat with sulphur by mixing and heating. Applies to India-rubber. To treat wood by a certain patented cooking process which is now defunct.

Vulcanized Fibre.—See "Fibre."

W

Wagon Bridge.—See "Bridge."

Wagon-way.—That portion of a floor set aside for wagon traffic.

Wakefield Piling.—Same as "Sheet Piling." See "Piling."

Wale, or Wale-piece, or Waling Strip.—A flat piece of timber laid horizontally for bracing upright timbers and for guiding them during driving, as in sheet piling.

Walking Crane.—Same as "Locomotive Crane." See "Crane."

Wall.—A structure or slab of small thickness, built in a vertical or nearly vertical plane.

Abutment Wall.—A wall in an abutment, or a wall serving the purpose of an abutment.

Breast Wall.—Same as "Retaining Wall," *q.v.*

Curtain Wall.—A thin wall. A partition wall that carries no superimposed load.

Division Wall.—Same as "Curtain Wall," *q.v.*

External Wall.—The outside wall of a structure.

Face Wall.—An exposed wall, a front wall.

Foot Wall.—A low wall at the foot of an embankment.

Head Wall.—The wall at the head or main part of an abutment.

Masonry Wall.—Any wall made of masonry.

Parapet Wall.—Same as "Parapet," *q.v.*

Puddle Wall.—A wall of plastic clay tamped in between two rows of sheet piling to prevent seepage of water.

Retaining Wall.—A wall built to sustain a lateral pressure, such as an earth thrust.

Slope Wall.—A thin wall of concrete or of flat stones laid upon the face of a sloping bank of earth to protect it from the erosive action of water.

Spandrel Wall.—A form of retaining wall built on an arch barrel to retain the spandrel filling.

Tail Wall.—The wall in a T-abutment set at right angles to the head wall to support the same.

Wing Wall.—One of the side walls of an abutment extending outward from the head wall in order to hold back the slope of an embankment.

Wall Knot.—See "Knot."

Wall Knot Crown.—See "Knot."

Wallower.—Same as "Trundle," *q.v.*

Wall Plate.—See "Plate."

Wane.—A beveled edge of a board or plank as sawn from an unsquared log.

Wane Tie.—See "Tie."

Warp.—A twist. To twist.

Warren Girder.—See "Girder."

Warren Truss.—See "Truss."

Wash Borings.—See "Borings."

Washer.—A flat disc or plate, having a central hole, placed under the head or the nut at the end of a bolt, in order to distribute the pressure over the wood or other soft material.

Beveled Washer.—A washer having one side beveled to compensate for the angle between the bolt and the timber through which the bolt passes.

Check Washer.—A washer devised to prevent a nut from turning.

Cup Washer.—A washer having a cup for receiving the nut of a bolt.

Friction Washer.—A thin ring of metal or other material inserted between two adjoining pieces, one or both of which rotate, in order to reduce the friction between them.

Washer.

Lip Washer.—A washer having a lip or projection that can be bent over after the nut is screwed on, thereby preventing the nut from working loose.

Lock-nut Washer.—A ring-shaped washer cut on one side and having the ends sprung laterally. Used for preventing a nut from turning.

O. G., or Ogee Washer.—A disc-shaped washer having its edge generated by an ogee curve, which was a standard curve used in Greek architecture.

Packing Washer.—A washer used between timbers to provide an open space between them when they are drawn together and bolted. The object in using them is to permit of a circulation of air between the sticks.

Plate Washer.—Any plate used as a washer.

Slot Washer.—A check washer having a slot cut at one side of the hole so that when the nut is tightened a nail can be driven through the slot, thus preventing the nut from turning.

Thickening Washer.—An additional washer used on a bolt to take up space.

Wash Mill.—An apparatus for washing sand, gravel, rock, etc.

Washout.—The destruction or displacement of a bridge, trestle, or embankment due to floods.

Waste.—Cotton used for wiping grease from machinery. Excess material from an excavation. To fail to utilize, in an embankment, material taken from a cut.

Water.—A colorless liquid chemically defined as H_2O. The run-off from a drainage basin as carried by the rivers and streams.

Extreme High Water.—The highest known water elevation of a stream or tide.

High Water.—The condition of a stream when discharging a large amount of water.

Low Water.—The condition of a stream when discharging a small amount of water.

Standard High Water.—An arbitrary high-water elevation either assumed or fixed by the War Department or some other authority.

Standard Low Water.—An arbitrary low-water elevation either assumed or fixed by the War Department or some other authority.

Water Cement.—Same as "Hydraulic Cement." See "Cement."

Water Column.—The water which rises in a vertical tube when the lower end is immersed in a current.

Water Crack.—A crack in steel due to the process of quenching it while red hot.

Water Crane.—See "Crane."

Water Cylinder.—See "Cylinder."

Water Gauge.—See "Gauge."

Water-hammer.—The shock resulting from the sudden stopping of the flow of water in a pipe.

Water Hemp.—See "Hemp."

Water Hose.—See "Hose."

Water Jet.—See "Jet."

Water Joint.—See "Joint."

Water Level.—See "Level."

Water Line.—See "Line."

Water-mark.—A mark or stain left on a bank, tree, or other object by a stream receding from high water.

Extreme High-water-mark.—A mark left by the highest known flood.

High-water-mark.—A mark left by any high water.

Low-water-mark.—A mark left by any low water.

Water Meter.—See "Meter."

Water Power.—See "Power."

Water Pressure.—See "Pressure."

Water-proof Paint.—See "Paint."

Watershed.—The line of separation between contiguous drainage areas. The divide. The height-of-land. Often, but incorrectly, used for drainage-area.

Water-table.—A belt course of masonry, moulding, or other projecting member with a sloping top, so placed as to throw off water from a wall.

Watertight.—Closed up to such an extent as to prevent the passage of water.

Waterway.—An opening or passage for water. A channel or stream of water as a means of communication. Space available for navigation.

Clear Waterway.—The horizontal distance over the water, measured perpendicularly to the centre lines of adjacent piers or fenders between the inner edges thereof.

Wattle.—To apply wattling to a pile dyke.

Wattling.—A screen used in river protection work, composed of long, slender poles, usually willow, passed horizontally and alternately behind and in front of a series of piles forming the dyke.

Ways, or **Launching Ways.**—Supports or tracks set on a slope, down which a caisson slides at the time of launching. Used also for the apparatus by which cars are unloaded on a hill-side.

Weak Iron.—See "Iron."

Wearing Floor.—See "Floor."

Weathering.—The process of seasoning by exposure to the elements.

Weather Joint.—See "Joint."

Web.—The portion of a truss or girder between and connecting the flanges, its function being principally to resist shear.

Open Web.—A web composed of a group of members instead of solid plates.

Solid Web.—A web composed of one or more solid plates.

Webbing.—The members or parts making up the web.

Web Members.—See "Members."

Web Plate.—See "Plate."

Compound Web Plate.—A web composed of several thicknesses of plates.

Web Splice.—See "Splice."

Web Stiffener.—See "Stiffener."

Web Stress.—See "Stress."

Wedge.—A solid having two inclined faces.

Guide Wedge.—A wedge-shaped apparatus used as a guide.

Launching Wedges.—Wedges used in supporting a caisson on the launching ways.

Striking Wedge.—One of the wedges inserted temporarily to support centres or falsework and knocked out after the work is completed.

Wedge-bearing Draw.—See "Draw."

Weep-hole.—A hole in a wall for draining the water that tends to accumulate at the back.

Weeping-pipe.—A pipe inserted in a wall or in any construction for the purpose of drawing off water that otherwise would accumulate.

Weir.—A dam which discharges water over its top or crest.

Weld.—To unit two pieces of metal by heating the ends until they become soft and then hammering them together. The part of the piece thus united.

Butt Weld, or **Jump Weld.**—A weld in which the pieces are butted against each other and then joined by welding.

Lap Weld, or **Scarf Weld.**—A weld in which the ends of the pieces are made to lap over each other and then joined by welding.

Welded Head.—See "Head."

Welded Joint.—See "Joint."

Welding.—The act or process of making a weld.

Welding Hammer.—See "Hammer."

Weld Iron.—See "Iron."

Weld Steel.—See "Steel."

Well.—A vertical opening or shaft in a crib or caisson for removing materials or for the passage of workmen.

Welt.—Same as "Butt Joint," *q.v.*

Wet Blowout. Same as "Wet Suction," *q.v.*

Wet Dock.—See "Dock."

Wet Puddling.—See "Puddling."

Wet Rot.—See "Rot."

Wet Suction.—A process of discharging material from the working chamber of a caisson by wetting it and placing it at the mouth of a discharge pipe through which it is blown by the pressure of the air.

Weyrauch's Formula.—A formula proposed by Weyrauch to determine the allowable unit stress when the member is subjected to a reversal of stress. It is no longer used in good American bridge engineering practice.

Wharf.—A structure or a level place along the bank of a waterway, upon which vessels lying alongside can discharge their cargoes.

Whatman's Paper.—See "Paper."

Wheel.—A circular framework or a solid disc capable of revolving about its centre.

Beveled Wheel.—A wheel having a sloping face.

Brake Wheel.—A heavy wheel furnished with cams to control the action of a trip hammer; the wheel of a band-brake.

Bull Wheel.—A large, horizontal wheel connected to the foot of a derrick mast for the purpose of turning the derrick with ropes leading to the hoisting engine.

Caster Wheel.—A wheel having its axle held in a stock or frame that turns about an axis perpendicular to its own.

Chain Wheel.—A wheel having projections or indentations on its face for the purpose of engaging the links of a chain.

Cog Wheel.—Same as "Gear," *q.v.*

Conical Wheel.—A wheel having a face conforming to the surface of a cone.

Crown Wheel.—A wheel with teeth set perpendicular to the plane of rotation.

Driving Wheel.—The main wheel which communicates motion to another or others.

Fly Wheel.—A heavy, revolving wheel for equalizing motion in machinery.

Friction Wheel.—A form of slip-coupling applied in cases where the variation in load is very sudden and great, as in dredges.

Gear Wheel.—See "Gear."

Hand Wheel.—A small wheel fitted to the hand for operating valves, etc.

Idle Wheel.—A wheel which runs loosely on its shaft.

Jockey Wheel.—A small wheel running against the rim of a grooved wheel to keep a rope, wire, or cable in the groove.

Joggle Wheel.—A wheel which has a wabbling motion.

Lantern Wheel.—A gear wheel composed of two parallel discs set some distance apart on an axle with round rods parallel to the axle, set at equal intervals around the periphery of the discs. These rods mesh with the teeth of another gear.

Leading Wheels.—The wheels in a locomotive placed in front of the drivers.

Pitch Wheel.—One of a pair of toothed wheels working together.

Rag Wheel.—A "Sprocket Wheel," *q.v.*

Ratchet Wheel.—A toothed wheel forming part of a ratchet mechanism. See "Ratchet."

Spoke Wheel.—A wheel having spokes instead of a solid web.

Spur Wheel.—Same as "Gear," *q.v.*

Toothed Wheel.—A wheel having teeth projecting from its face.

Traveler Wheel.—One of the wheels supporting a traveler on its track.

Unbalanced Wheel.—(Statically) Any wheel in which the centre of rotation is not coincident with the centre of gravity. (Dynamically) Any wheel in which the

Wheel.

centre of rotation is not coincident with the centre of gravity and the centrifugal force of the rotating system does not reduce to zero.

Wheelbarrow.—A small hand vehicle for transporting materials, consisting of a bed or box resting on two handles, supported by a wheel at one end and the operator's hands at the other.

Wheel Base.—See "Base."

Wheel Carriage.—See "Carriage."

Wheel Chain.—See "Chain."

Wheel Concentration.—See "Concentration."

Wheel Flange.—See "Flange."

Wheel Frame.—See "Frame."

Wheel Friction.—Same as "Rolling Friction." See "Friction."

Wheel Guard.—See "Guard."

Wheel Load.—See "Load."

Wheel Tread.—See "Tread."

Wheel Wrench.—See "Wrench."

Whin.—An early form of windlass for hoisting.

Whetstone.—A stone for sharpening tools by rubbing.

Whipple Truss.—See "Truss."

Whiskey Jack.—See "Jack."

White Iron.—See "Iron."

White Lead.—See "Lead."

White Lime.—See "Lime."

White Metal.—See "Metal."

White Pine.—See "Pine."

Wick Packing.—See "Packing."

Wide Cross-cut Saw.—See "Saw."

Wild Steel.—See "Steel."

Williot Diagram.—A graphical method for determining the deflections of a framed structure. See Chapter XII.

Winch.—Same as "Windlass," *q.v.*

Hand Winch.—A winch operated by hand power.

Wind Bracing.—See "Bracing."

Winding Drum.—See "Drum."

Windlass.—A winding machine consisting of an axle mounted in a frame, and turned by a crank, a wheel, or radial bars at the end, and which winds up a rope causing a load to be moved.

Chinese Windlass, or **Differential Windlass.**—A windlass having an axle or barrel with different diameters, so that the rope winds up on the larger and unwinds from the smaller, the difference between the two motions resulting in a slow lifting of a heavy load.

Spanish Windlass.—An extemporized purchase made by winding a rope around a roller and inserting a lever in a hitch or bight of the rope. By heaving round the lever a considerable torsional moment is produced.

Windlass Jack.—See "Jack."

Wind Load.—See "Load."

Wind Pressure.—See "Pressure."

Wind Shake.—A crack or fissure in a piece of timber occurring during its growth.

Wind Stress.—See "Stress."

Wind Truss.—See "Truss."

Windward.—The direction from which the wind comes.

Windward Chord.—See "Chord."

Windward Truss.—See "Truss."

Wing Abutment.—See "Abutment."
Wing Nut.—See "Nut."
Wing Wall.—See "Wall."
Wiper.—Same as "Cam," *q.v.*
Wire Bridge.—Same as "Suspension Bridge." See "Bridge."
Wire Cable.—See "Cable."
Wire Cloth.—Wire net having a small mesh.
Wire Gauge.—See "Gauge."
Wire Iron.—See "Iron."
Wire Joint.—See "Joint."
Wire Nail.—See "Nail."
Wire Rope.—See "Rope."
Wöhler's Laws.—A series of laws based on Wöhler's experiments on the fatigue of metal. It is now conceded that they do not in any way apply to bridge designing, because they deal solely with metal stressed beyond the elastic limit and are not applicable otherwise.
Wood.—The hard, fibrous substance which composes the body of a tree.
Cross-fibred Wood.—A wood in which the fibres run obliquely to the axis of the tree, reversing direction in different layers and thereby producing a crossed effect.
Cross-grained Wood.—Same as "Cross-fibred Wood," *q.v.*
Curled Wood.—A wood in which the fibres are fine and run in folds or ridges, producing a curly effect in some places.
Dry Rotten Wood.—Wood subject to dry rot. See "Rot."
Hard Wood.—A term arbitrarily applied by the lumber trade to woods of the broad-leaved trees.
Heart Wood.—The older and central part of a log, usually darker than the sapwood.
Lance Wood.—A light, yellow-colored wood used in surveying rods.
Sap Wood.—The outer and lighter colored portion of a timber containing sap.
Soft Wood.—An arbitrary term for wood from coniferous trees.
Wood-Boring Machine.—See "Boring Machine."
Wood Screw.—See "Screw."
Work.—The overcoming of resistance through space as measured by the product of the force and the distance, in its own direction, over which it acts. Also used as a general term for any engineering construction or the operations connected with such construction.
Field Work.—Surveying and kindred operations in the field.
Herringbone Work.—Masonry work done according to the Herringbone system. See "Herringbone."
Iron Work.—Any construction using iron members.
Job Work.—Work done by the job.
Joggle Work.—Masonry construction in which the stones are internotched or keyed.
Ladder Work.—Work that is done from a ladder.
Leaf Work.—The ornamental work done on cast-iron which is sometimes used on portal bracing in bridges for appearance only; also scroll work on cast-iron columns and lamp posts.
Machine Work.—The shaping, fitting, and dressing of metal such as drilling, planing, turning, milling, and grinding done by machinery.
Mat Work.—A general term for extended mattress construction used in river protection.
Neat Work.—The work or part of construction inside of the "neat line," *q.v.*
Ornamental Work.—That portion of a structure which is added to the main portion in order to enhance its æsthetic qualities.
Pile Work.—A general term covering pile construction.
Rock Work.—Rock excavation. Also used for "Masonry," *q.v.*

Work.

Rubble Work.—Same as "Rubble Masonry." See "Masonry."

Trestle Work.—A general term covering trestle construction.

Working Chamber.—See "Chamber."

Working Drawing.—See "Drawing."

Working Load.—See "Load."

Working Pit.—See "Pit."

Working Shaft.—See "Shaft."

Working Stress.—See "Stress."

Working Unit Stress.—See "Stress."

Workmanlike.—In the manner of a skilled workman.

Workmanship.—The art or skill of a workman, or the quality of the execution of the work.

Work of Friction, or Work Done in Overcoming Friction.—The work done by a force in moving against a frictional resistance. Loosely termed "Work of Friction."

Work of Resilience.—The work done by a deformed elastic body in recovering its normal condition. Theoretically, this is equal to the energy stored in the body during its deformation, providing that the elastic limit of the material has not been passed.

Worm.—A helix or helical gear on a shaft which meshes into the worm gear.

Worm Gear.—See "Gear."

Worm Rack.—See "Rack."

Worm Shaft.—See "Shaft."

Worm Wheel.—Same as "Worm Gear." See "Gear."

Worm Work Dressing.—See "Dressing."

Wrench.—A tool for turning nuts, bolts, and pipes, consisting of a bar or handle having jaws to fit the nut, bolt, or pipe.

Alligator Wrench.—A wrench with fixed spreading jaws, having an inside roughened surface, suggestive of the open mouth of an alligator.

Claw Wrench.—A wrench with a claw end.

Combination Wrench.—A wrench having jaws to fit both nuts and pipes.

Diagonal Wrench.—A wrench in which the axis of the jaws is set obliquely to the handle.

Double Wrench.—A wrench having a set of jaws at each end.

Forked Wrench.—A wrench having a pair of jaws at one end of a bar, while the other end tapers to a point.

Key Wrench.—A socket wrench having a cross handle; also a wrench having one sliding jaw held in place by a key.

Monkey Wrench.—A wrench having an adjustable jaw moved by a screw.

Open-end Wrench.—Same as "Forked Wrench," *q.v.*

Pipe Wrench.—A wrench having its jaws shaped and adapted for holding a pipe.

Ratchet Wrench.—A wrench provided with a handle engaging a ratchet.

Socket Wrench.—A wrench having a handle and shank with a recess in the latter to fit the nut.

S-Wrench.—A wrench having a bent handle like the letter S.

Tap Wrench.—A cross-handled wrench used for turning a tap.

Track Wrench.—A long-handled, forked wrench, used by trackmen for tightening nuts on rail joints.

Wheel Wrench.—A wrench having a wheel-shaped handle.

Wrench Hammer.—See "Hammer."

Wring Fit.—A fit between two parts which are so accurately matched that they have to be put together with a twisting motion.

Wrought Iron.—See "Iron."

Wrought Iron Pipe.—See "Pipe."

Wrought Nail.—See "Nail."

Wye.—A support for the telescope in the engineers' level, having the form of the letter Y. A railroad siding in the form of the letter Y; used for turning locomotives and trains.

X

X-Bracing.—See "Bracing."

Y

Y.—An arrangement of railroad tracks, resembling the letter Y, which is used for turning trains around. Sometimes spelled "Wye."

Yardage.—The contents or amount of material expressed in cubic yards.

Yellow Ochre.—See "Ochre."

Yield Point.—That point, or intensity of stress, at which the rate of stretch begins to increase rapidly.

Y-Level.—See "Level."

Yoke Riveter.—See "Riveter."

Young's Modulus.—Same as the "Modulus of Elasticity." See "Elasticity."

Z

Z-Bar.—See "Bar."

Z-Bar Iron.—See "Iron."

Z-Column.—See "Column."

Zigzag Riveting.—Same as "Staggered Riveting." See "Riveting."

Zinc White.—An oxide of zinc, in the form of a white powder, which is used as a base for paint.

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